Incorporating Climate Change into Inland Fisheries Management and Policy Development: A Systematic Review

by

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ABSTRACT

The impact of climate change on inland fisheries has received critical attention in science and policy cycles. Despite this attention, the consequences of these impacts are difficult to predict due to the complex dynamics of these systems, their inherent uncertainties and the long timescales upon which change occurs. Additionally, inland fisheries are often influenced by multiple external drivers which are difficult to identify and account for in assessing and predicting change. Despite a growing body of literature on climate change impacts on fisheries, few comprehensive syntheses exist. This thesis applies a systematic literature review to answer the question whether climate change is incorporated into inland fisheries management and policy development. The review found that despite the growing attention, the literature in the field could still be described as insufficient. The review revealed that in general studies did not integrate climate change into management or decision-making, and even fewer studies attempted to identify adaptive options. Integrated approaches or responses that incorporate multiple drivers of change and account for multiple sources of uncertainty are needed for policy makers and stakeholders. The complexities of these socio-ecological systems require deliberate integration of climate change in the management of inland fisheries.

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ABBREVIATIONS

ACIA	Arctic Climate Impact Assessment
DPSIR	Drivers-Pressures-State-Impact-Response
EEA	European Environment Agency
ES	Ecosystem services
FAO	Food and Agriculture Organization
FES	Freshwater Ecosystem Services
GDP	Gross Domestic Product
GEO	Global Environment Outlook
GHG	Greenhouse Gas
IF	Inland Fisheries
IPBES	Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
ITQs	Individual Transferable Quotas
MA	Millennium Ecosystem Assessment
MPAs	Marine Protected Areas
MUN	Memorial University of Newfoundland
NGOs	Non-Governmental Organizations
OECD	Organisation for Economic Co-operation and Development
SSF	Small-Scale fisheries
TACs	Total Allowable Catches
UNEP	United Nations Environment Programme
UNSD	United Nations Commission on Sustainable Development
UV-B	Ultraviolet B
WWF	World Wildlife Fund for Nature

Chapter 1 Introducing the research

1.1 Background

It is widely known that most fishing activities occur at sea under marine conditions; however, significant food resources are also derived from inland fisheries in freshwater resources including rivers and lakes. Inland waters, as defined by the Food and Agriculture Organization (FAO, 2014), are lakes, rivers, streams, reservoirs and other landlocked waters such as brooks, estuaries, and other water bodies inhabited by a diversity of species and providing various livelihoods and wellbeing to people and local communities. Herein, the term inland fisheries refers to the fishing operations taking place in freshwater. FAO uses the term inland fisheries to encompass both inland capture and aquaculture fisheries (Rana et al., 1998). These sectors contribute over 40% to the world's reported finfish production from around 0.01% of the total volume of water on earth (Lynch et al., 2016; Stiassny, 1996). Inland fisheries are generally synonymous with freshwater in terminology, even though there is a slight difference given that inland waters also include land-locked saline water bodies (FAO, 2014; Lynch et al., 2015). Most inland fisheries are undertaken in freshwater bodies around the globe and this thesis is premised on this conception.

Freshwater takes up only about 2% of all water on earth and most of it is accumulated as snow or ice in polar areas. Inland waters comprise approximately 0.01% of the total volume of water on earth (Stiassny, 1996). Inland fisheries, also termed inland capture plus aquaculture (Rana et al., 1998), account for about 40% of the fish species, of which 20% are vertebrate species (Helfman et al., 2009). Inland fisheries contribute about 10%–12% to the annual global fisheries production (FAO, 2016). Together, inland capture fisheries and aquaculture contribute to about 25% to the world's fish production (Brummett et al., 2007). The sector has been developing for a long time and has shown very dynamic states. The inland fisheries sector is not only highly dynamic, it is also rich in diversity. Capture fisheries are fisheries where the fish living naturally in a body of water are harvested, while aquaculture is another part of inland fisheries where fish are farmed in different ways; one of the common practices is cage aquaculture. Aquaculture systems can be divided into extensive, semi-intensive, and intensive (De Silva & Hasen, 2007). Extensive aquaculture is the least among the three, as it requires less effort. It involves the farming of fish in the sea, rivers and other open water bodies. Intensive aquaculture is the most controlled form of fish farming where technology is heavily used to farm fish in closed tanks. Semi-intensive aquaculture falls in between these two, where the natural feed level available to fish are supplemented (Bostock, et al., 2010; Naylor, et. al., 2000). Inland pond aquaculture is commonly used in countries like China and India and is recognized as having the largest impacts on the environment among the different forms of farming ways (Sumaila, Bellmann & Tipping, 2016).

More than 6% of the global capture fisheries and aquaculture production comes from inland capture fisheries from 150 countries, according to a report by FAO (FAO, 2003). Inland capture fisheries normally consist of commercial or industrial fisheries, small-scale or artisanal/subsistence fisheries and recreational/sports fisheries. Though in many countries there is a mix of these types, some are more inclined toward either commercial or subsistence or recreational. For example, the recreational fisheries in many parts of Canada are done on inland waters. In most developing countries, inland fisheries form an important subsistence for the people, especially in landlocked nations. And in countries like China, which is considered a dominant player, commercial inland fisheries are an important part of their economy (Zhao et al., 2015). Most of the inland fisheries' catch is consumed locally and domestically. When inland fisheries is taken entirely, the major locations are found in developing countries, such as China, India, Bangladesh and Indonesia, among others. Statistics from FAO (FAO, 2003) demonstrate that inland capture fisheries production comes from different continents: "5.8 million tons from Asia; 2.1 million tons from Africa; 0.3 million tons from Europe and South America each; 0.2 million tons from North America; and 22 thousand tons from Oceania" (see Figure 1.1).

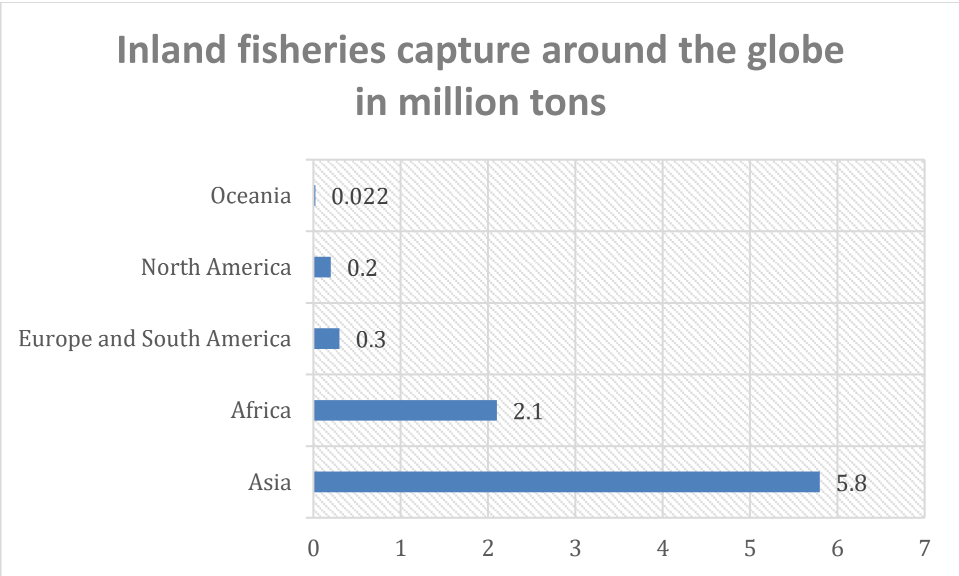

Figure 1.1 Inland fisheries capture around the globe

Source: Adapted from FAO (2003).

Twenty countries accounted for 84% of the total global inland capture fisheries production in 2003 with the top producers being China (2.1 million tons), India (1.0

million tons), and Bangladesh (0.7 million tons). Based on production, most of the important inland fisheries countries are in Asia and Africa (FAO 2003, p. 60). However, the world's inland capture fisheries production is decreasing based on previous harvests for the past 20 years (FAO, 2003).

Inland fisheries are rapidly expanding and competing for natural resources with other freshwater usage in lakes and rivers. This is partly due to limited freshwater availability on earth and to overuse, wastage and competing interest for freshwater resources. For example, human beings generally give significant freshwater resources priority for agriculture and hydroelectric power plant developments. It is postulated that the planet is currently entering a freshwater crisis, and this challenge is predicted to increase as human beings encourage urbanization and pollution impacts increase (Fickle et al., 2007). The fact that only a limited and small amount of freshwater is available compared to the saline water in oceans is an obvious challenge faced by inland fisheries. Moreover, strong competition with other water usages for freshwater resources plus the growing population put more pressure on inland fisheries resources. A number of works suggest that inland fisheries are in an unfavorable place and the complex internal and external factors together add to the more severe current situation (Fickle et al., 2007; Suuronen & Batley, 2014; Zhao et al., 2015).

1.2 Climate change's impacts on inland fisheries

Climate change has profound impacts globally on many areas including freshwater ecosystems and fisheries; there is much evidence that the changing of climate is presenting major challenges to humankind (Reist et al., 2006; Strayer & Dudgeon, 2010; Blaber & Barletta, 2016; Jackson et al., 2016). In recent times, dating from the industrial revolution, there has been an increased tendency to use fossil fuels as an energy source. Indeed, more than 80% of the world's energy now comes from fossil fuels (ACIA, 2004). Human beings benefit from fossil fuels as a relatively cheap power source, but their combustion does produce greenhouse gases, most notably carbon dioxide, methane, and nitrous oxides; all of which are linked to global climate change. These sources, in combination with factors like solar radiation and volcanic eruptions, are drivers of climate change (Rosenberg, 1988). Modern model predictions show a more alarming fact that global climate change will continue, even if greenhouse gas emissions decrease or cease (Ficke et al., 2007). This assertion may be attributed to the already accumulated emissions, which can still exert changes to climate even when current activities are halted or slowed down. The role of natural climate change cannot also be discounted in the view that the changes are inevitable to some extent. One trend of climate change, global warming, is widely recognized and debated. Although temperature change scenarios vary by regions, data indicate a clear warming trend in Europe (Schröter et al., 2005). In other regions of the globe, there is also evidence that such changes are expected to occur. For example, warming temperatures are also projected to change snow to rain in precipitations at higher latitudes in North America (Healey, 2011; Mote et al., 2014), and warming effects in the Arctic are predicted to melt ice cover and produce more streams, which will force salmonid species to look for more suitable habitats (Healey, 2011). Significantly, global air temperature has increased nearly twice over the past 50 years (1955–2005) compared to the previous 100 years (IPCC, 2007). It is also reported that heat stress is one of the major environmental concerns under global warming conditions, and rising temperature has led to mortality of animals including aquatic fishes (Brander, 2007; Matthews et al., 2017).

Climate change affects aquatic systems and the uses of aquatic resources by influencing the hydrologic cycle through attributes such as precipitation, evaporation and evapotranspiration. Higher temperatures and insolation can result in increase of water loss from freshwater systems because evaporation rates may outstrip input from increased precipitation (Allan et al., 2005). Climate change may also lead to increased UV-B and deeper penetration into water bodies (Allan et al., 2005; Reist et al., 2006). Increased UV radiation levels affect the survival of certain fish species, normal pace of fish growth, and bioavailability of dissolved organic carbon (ACIA, 2004; Reist et al., 2006). For example, increased radiation in surface waters is likely to disrupt fish development and cause damage to young fish, consequently decreasing survival, or forcing fish deeper thus slowing growth (Reist et al., 2006). Climate change is also regarded as one of the contributors to altering the normal natural trophic status of aquatic systems leading to excessive nutrients loss and even loss of fish species in water bodies (Bertahas et al., 2006). Even though eutrophication usually comes from sewage discharge and agricultural or urban chemical runoff of nutrients and sediments, climate change is believed to increase the water temperature and accelerate productivity of the water body itself by increasing nutrient cycling, algal growth and bacterial metabolism (Allan et al., 2005; Sala et al., 2000). In addition, changes in the oceans will, to some extent, also affect inland fisheries. There is evidence that sea level rise will directly influence the coastline habitats, and ocean temperature rise, and acidification will also affect inland fisheries which are in the nearshore sites (Blaber & Barletta, 2016; Jackson et al., 2016). Unfortunately, our knowledge of how climate change impacts individual fish species, fish populations, and local communities has not given us a complete and clear picture, but the relevant studies are growing (Lynch et al., 2015). Although UV-B, eutrophication and acidification effects have been verified, the interaction among them is expected to cause negative results for natural systems; these interactions remain unresolved and require further studies (Allan et al., 2005). In summary, changes related to inland waters include increasing temperature, increased toxicity of pollutants, decreased dissolved pollutants. These affect the health of freshwater life and relevant ecosystems and productivity of fisheries. The climate change impacts on freshwater fishes also include fish physiology and a wide range of fishes in different regions of different temperatures globally, according to an extensive study (Ficke et al., 2007). For example, increasing temperatures are predicted to trigger declines and even extirpations of Arctic adapted fish (ACIA, 2004).

The phenomena above reveal the trend that climate is changing, and some important variables will affect freshwater ecosystems and inland fisheries. Water temperature, its quality and quantity are all affected by changing climate, so the fish population, distribution, production and quality can also be predicted to be affected profoundly by climate change.

Because the loss of biodiversity ranks among the top threats to human well-being, there is a pressing need to assess and respond to this issue. The international Convention on Biological Diversity (UNEP, 1994) defines biodiversity as "the variability among living organisms from all sources, including ... terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems. (UNEP 1994, p.16)" The term "biodiversity" therefore represents the richness and the variety of life on the planet and passes the information of ecological and species diversity and the human responses to it. Despite the importance of biodiversity in maintaining ecosystem productivity and in providing a myriad of ecosystem and economic services, the 2016 Living Planet Report highlighted climate change as one of the key drivers of biodiversity loss (World Wide Fund for Nature [WWF], 2016).

Moreover, the issue is complicated by human interactions and interventions that putatively contribute to global warming. Various scenarios have been considered as a guide to help decision makers identify potential impacts of different policy options. Efforts by the Millennium Ecosystem Assessment (MA) initiatives and more recently by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) offer a means to assess the state of the planet's biodiversity, its ecosystems, and the essential services they provide to society (MA, 2005). Based on these global assessments, freshwater fishes are among those species that are highly vulnerable to anthropogenic impacts and climate change events (Strayer & Dudgeon, 2010).

Strong evidence that have accumulated worldwide in the past few years reveal that freshwater biodiversity loss is not a theoretical issue but an ongoing and accelerating catastrophe facing us (Strayer & Dudgeon, 2010). According to The Nature Conservancy Great Lakes Program (1994), the importance of addressing impacts on fish and other biota can be classified into three categories: biodiversity loss weakens and destroys healthy ecosystems, biodiversity is the precious and irreplaceable valuable natural resources, and human beings benefit from varieties of ecosystem services (Day & Roff, 2000).

The adoption of inland fisheries policy has existed for a long time since people gained more experience from the world environment reality and became aware of limited fishing resources and the reality that fisheries should be regulated. Modern governments adopted centralized regulations to control the inland fisheries at the national level (Welcomme, 2008), even though it has long been perceived by the public that inland fishery resources are common and accessible to everyone. There are some practical problems of centralized systems because of their inconsistencies and the fact that they are less effective than expected (Welcomme, 2008). Older fisheries management models are all from centralized systems and often assume that natural resources are inexhaustible, which apparently neglects the environmental impacts on fish populations.

The rate of overexploiting natural resources is alarming and makes it a great concern for the public that fishing resources are also facing the same issue, as increasing numbers of marine and inland fisheries are regarded as overfished. FAO observed and indicated in 1999 that most of the rivers, lakes and reservoirs are overfished (FAO, 1999a). Increasing demand and subsidized huge fishing capacity, plus technology development have led to overfishing on a large scale (Sumaila, Bellmann, & Tipping, 2016). As the problem of overfishing emerged, fishing management and governance systems have been established accordingly, to counteract the impacts of the "common pool" nature of fisheries. Policy makers of many countries imposed stricter laws and policies to avoid environmental degradation to ensure sustainable development of the fisheries industry. Lots of different management tools and approaches have been developed and adopted over time such as setting of total allowable catches (TACs), limited entry programs, quotas regulations, spatial planning and access rights to marine protected areas (MPAs). For example, the North Pacific halibut fishery in the US and Canada is managed with ITQs (Soliman, 2014). In China, the “Zero Growth” and “Negative Growth” tools have been adopted since 2000 as a form of TAC (Shen, G., & Heino, M.,2014). In all areas, the focus on overexploitation remains a primary issue in much of the inland fisheries management literature (Suuronen & Bartley, 2014).

However, governmental actions are facing doubts and challenges because fisheries related policies and regulations apparently have shown poor governance practices, and inland fishery resources and aquatic environments continue to degrade in many areas of the world (FAO, 2010). Agnew et al. (2009) pointed out that weak governance activities facilitate illegal fishing and the use of destructive fishing practices, as demonstrated by the large amount of illegal and unreported fishing on a global scale. The FAO attributes much of these unreported fisheries to small scale activities (Drammeh, 2000). At the same time, it has been realized that centralized management of inland fisheries, coupled with limited and difficult-to-manage small scale dominance of the sector, generally is a failure (Soliman, 2014). Lessons from past negative experiences, including the social role of these fisheries to livelihoods and how those impact successes of regulations, indicate that consideration of biology alone is not sufficient to deal with fisheries. The challenging situations faced by inland fisheries call for appropriate inland fisheries management and conservation measures in the context of climate change.

Global warming influences physical and biological processes at local, regional, and global scales. The effects of climate change on natural ecosystems have been evidenced broadly across ecosystems, societies and economies. While considerable attention has been given to atmospheric and terrestrial systems, it is also apparent that climate change has had profound implications for aquatic systems including freshwater habitats and the goods and services they provide. There is a general consensus that among the myriad of ecosystem services, freshwater and its fish biota represent one of the most valuable resources to society. As such, there is a pressing need to better understand how freshwater ecosystems function and how inland fish resources might be managed considering changing environmental conditions. Ruby and Ahilan (2018), Mohanty et al. (2010) and Lynch et al. (2015) are among those who posit that climate change will have significant influence on the ecology and future management of inland fisheries. The recognition that climate will act as a strong driver of inland fisheries has triggered a sense of urgency and a call for adaptation measures to address the potential impacts of climate change on natural ecosystems (Palmer et al., 2008; Punt et al., 2013). Approaches to incorporating climate change in decision-making is one means to address the high level of uncertainty and complexity associated with the management of inland fisheries.

Although data are limited, and serious knowledge gaps remain, Food and Agriculture Organization (FAO) (2009) and others (Chu et al., 2005; Rieman et al., 2007; Lynch, 2010; Eby et al., 2014) have documented how climate change is expected to impact fisheries and how it will further complicate resource management. Many drivers including climate change combined make it more difficult for policy makers and stakeholders to devise suitable adaptive options and proactive measures for fisheries management. This challenge is particularly pressing for inland fisheries where the systems are poorly understood, and less attention has been directed compared to marine fisheries. Several studies have pointed to the immediate need for new tools and approaches to deal with challenges and uncertainties associated with the management of inland fisheries (Cowx & Collares-Pereira, 2004; Lynch, 2013; Lynch et al., 2015).

Among the rich literature dealing with the governance and management of fisheries, many publications focus on the marine sector (Beddington, Angew & Clark, 2007; Dulvy et al., 2011; Johnson & Welch, 2009). In contrast, there is a paucity of information on inland fisheries. Inland fisheries are important because they provide livelihood and food resources for the poorest of the world, yet their value to society is often ignored (Dulvy et al., 2011). Current inland fisheries management practices are generally not that effective (Lynch et al., 2017; Myers et al., 2017). New approaches are required to effectively manage inland fisheries that incorporate the effects climate change and other drivers have on the management and policy development processes.

1.3 Problem statement

Research on impacts of climate change on aquatic ecosystem services has grown increasingly (Mooney et al., 2009), particularly in coastal and marine areas (Maes et al., 2013). However, the effects of climate change on inland fisheries has been given less attention globally, despite the importance of protein production in both fisheries and aquaculture systems (Beddington, Angew & Clark, 2007; Welcomme et al., 2010, FAO, 2016). The global community requires a better understanding of the effects of climate change on inland fisheries ecosystem services and how to integrate this knowledge into decision-making and policy development processes. To address this knowledge gap, the thesis asks: are climate change effects integrated into inland fisheries management and policy development? To answer this important question, three objectives will be pursued: a. to conduct a systematic literature review to answer the question, is climate change appropriately integrated into inland fisheries management and policy development; b. to determine the degree of integration of climate change knowledge into inland fisheries management and policy development using the DPSIR model as an evaluation framework; and c. to identify gaps and recommend key directions for future research.

1.4 Structure of the thesis

The thesis is structured into four chapters. The four chapters are systematically designed to ensure coherence and continuity in the work. The chapters are as follows: Chapter one provides the reader with the necessary background to understand the nature and extent of inland fisheries and the degree to which they have been impacted by climate change and are predicted to be impacted. It comprises headings such as the introduction to the study, statement of the problem, research questions, research objectives, and outline of the study. Chapter two describes the methodology used. Chapter three presents the results of the systematic literature review. This chapter provides the reader with a comprehensive overview of the degree to which climate change is incorporated in inland fisheries management and decision making and helps place that information into perspective. Specifically, the review considers works that address the need for managers of inland fisheries to incorporate climate change into their management regimes. The chapter discusses key issues that will help elucidate the state of knowledge surrounding this topic. This is important in helping understand where gaps exist, and to enhance understanding of the ensuing chapters. Specific areas, including inland fisheries in general, climate change impacts on inland fisheries, inland fisheries management incorporating climate change, are discussed in this chapter. Chapter four includes the conclusion, limitations of the study and recommendations for further research.

Chapter 2 Methods

This thesis adopted a meta-analysis method to systematically review the literature. The Driver-Pressure-State-Impact-Response or DPSIR framework is used as a filter to describe the degree to which the climate change as an agent of change has been integrated into inland fisheries management and policy development. The literature search has used the databases from online library of Memorial University of Newfoundland. In this chapter, the researcher outlined the procedure used to undertake the review. In the first part of the chapter, the analytical and theoretical framework -DPSIR- is introduced. The second part of the chapter then explains the step-by-step procedures for the review.

2.1 DPSIR framework

To answer the research question, the Drivers-Pressures-State-Impact-Response (DPSIR) framework is used as a tool to investigate the degree to which integration has occurred. The DPSIR framework was first used to describe relationships and interactions between society and the environment (Gabrielsen & Bosch, 2003). The framework arranges relevant environmental indicators into categories to help explain the relationships between indicators within the conceptual model. This framework has also been used by several researchers to monitor and integrate the many components that underlie ecosystem processes. As such, the DPSIR framework is useful in describing the relationships between the origins and consequences of environmental problems. The framework can provide insights into the many links that occur among DPSIR elements. The DPSIR model has been used as an analytical framework to systematically review and assess important resources sectors impacted by drivers and pressures, including water issues (Borja et al., 2006; Mattas & Panagopoulos, 2014), biodiversity issues (Maxim et al., 2009), and ecosystem services issues (Atkins et al., 2011). Thus far, the framework has had no or limited use in the field of inland fisheries.

The DPSIR (Drivers-Pressures-State-Impact-Response) framework originated from the Pressure-State-Response (PSR) concept, proposed based on the concept of cause and effect phenomena by the Organization of Economic Cooperation and Development (OECD, 1993) for environmental reporting. PSR is the earliest form used as a framework, which was expanded from Rapport and Friend's (Rapport & Friend, 1979) stress–response model. The PSR model describes in detail how human-induced pressures are exerted on the current situation of the environment (State) and social responses to the changed environmental conditions (new State) for adaptation (OECD, 1993). PSR is a very simple cause-effect relationship in a system and it can be linear or cyclical (Bell & Morse, 2003). As Bell and Morse (2003) mentioned, the PSR linear cause and effect relationship can be described as pressures or driving forces' influence on the existing environmental states and the responses to the states can become new states. The cyclical PSR model incorporates a 'benefit' element (for example, aesthetical or recreational value as fishing or boating) (Bell & Morse, 2003). This benefit aspect will drive the human activity to reach the required situation. Changes imply that there are inevitable factors in the PSR model which can be opportunities or threats at the same time, the invention of new technologies is a good example. Desired benefits or values are the drivers for promoting changes. The model depicts a circular picture of how these benefits and environmental conditions are intertwined and how the respective components interact.

There are some problems in this model despite it becoming more and more popular in improving scientific problem-solving. Spangenberg and Bonnior (1998) argued that the “response” is inclined as it let institutional authorities make short-term policies decisions which solve immediate problems but undermine the function of long-term development and prohibit the proactive strategies for the responses. A major problem is that the PSR model only pays attention to anthropogenic pressures without considering the natural variables in its classification scheme (Bowen & Riley, 2003). The fact that most of PSR model indicators sometimes cannot indicate the various causalities and interactions inherent in sustainable development (Gallopin, 1997; Hardi et al., 1997) is also regarded as another potential problem, resulting in one-dimensional angle thinking. However, multiple pressure indicators can be influenced by a single state indicator and one single indicator can be characterized as either pressure or driver (Hardi et al., 1997). Even though more indicators can be considered to avoid this, it is still criticized as a highly mechanic and simple model which confines sustainable development to a narrow space by damaging its organic and dynamic nature (Gallopin, 1997). The UNSD (United Nations Commission on Sustainable Development) modified the PSR model in 1997 by adding driving forces (or Drivers) to this framework. The DPSR model incorporated pressures caused by natural systems in addition to existing social, economic and demographic pressures (Carr et al., 2007). Driving forces can be aspects such as demand for water, food or other resources. The demand for these needs’ satisfaction can lead to the pressures within the framework. Another problem arising is that changes for the states are not clearly clarified both in the PSR and DPSR models. There is no reasonable explanation behind the responses to changes because the changed states of the environment are not described (Bowen &

Riley, 2003). Social impacts (economic values) of the changing states are normally regarded as the prioritized variables for institutional authorities to make responses.

Through time, DPSIR evolved to become a formalized framework to define the interactions among drivers, pressures, states, impacts and responses and how they impact on the environment from a systemic perspective (Kelble et al., 2013). The European Environment Agency (EEA) and the European Statistical Office have applied this framework to describe societal and environmental relations and it still serves the function of environmental data collection, categorization and dissemination, as well as indicators development (EEA, 1997). The DPSIR framework was later adopted as the foundation of integrated environmental assessments in the UN GEO4 DPSIR Framework (UNEP, 2007), which focuses on the combination aspects of environmental and social factors. Drivers can be referred as driving forces which have direct impacts on the environment (UNEP, 2007).

The framework is widely used in the fields of global change, ecosystem research, and sustainable environmental analysis, and to investigate relationships between causes and effects among intertwined environmental, economic and social systems components (Kristensen, 2004). For example, Krajnc and Glavic (2005) established a standardized set of sustainability indicators for companies, involving all major aspects of sustainable development. Its indicators can also be used in assessing environmental sustainability issues from different perspectives (Sun et al., 2016; Reed et al., 2006; Singh et al., 2009).

This framework describes that human needs such as population development and economic growth act as drivers (D) in environmental fields, which impact (I) on human activities and exert pressures (P) on them; as a result, the status (S) of the effects will change, which calls for the response (R) to the status. In other words, the influence of the impacts (I) requires the changing of the status (S) or correspondent responses (R) in dealing with environmental issues. This framework has an inner evaluating structure with key indicators to direct policy makers to understand the relationships among the overall system and how drivers and pressures work; thus, DPSIR helps them adopt reasonable and effective strategies on environmental problems and influence the making of political choices according to the results of their analysis (Timmerman et al., 2011). The DPSIR framework therefore is a useful and an important tool for examining complex associations and interactions among freshwater fisheries resources and other social and economic elements because it offers a systematized way for understanding the drivers, effects and impacts, and responses to the changing climate (Hou et al., 2014). Thus, DPSIR framework is used in this thesis to identify drivers, impacts and assess how projected impacts and associated uncertainties can effectively help to analyze the data collected from databases. The uncertainties incorporated in the definition of “state” and the extent to which they are considered in decision making will also be assessed because this can serve as a guide for policy makers and managers to develop policies and predict the further possible climate change scenarios better to reduce the climate change impacts and make inland fisheries more sustainable. It is helpful to ask the following questions in determining each component by using the DPSIR framework (UNEP, 2014).

Table 2.1 Questions for determining DPSIR components

Purpose	What is the purpose of the assessment or what is being assessed?
Drivers	What drivers (D) led to these pressures (P)?
Pressures	What are the pressures (P) responsible for the present state of the environment (S)?
State	What is the state of the environment (S) or part of the environment (e.g. habitat)?
Impacts	What are the impacts (I) of the present state of the environment (S) on society?
Responses	What actions or responses (R) should be taken?

Source: UNEP, 2014

The DPSIR framework is used in this thesis to explain the logical thinking following four steps from the perspective of impacts of changing climate on inland fisheries. Step 1 - What is happening to inland fisheries and why? (current status, drivers and pressures). Step - 2 What are the consequences for the environment and humanity? (Impacts). Step - 3 What is being done and how effective is it? (Responses). Step - 4 Current human responses and further recommendations. (Responses)

As explained above, the DPSIR framework has been applied by EEA and other researchers to assess the causes, consequences and responses to environmental changes in a comprehensive manner. In the context of freshwater ecosystem, the general Drivers of fisheries management are the climate change and non-climatic factors, such as anthropogenic influences. Each of the Drivers can cause one or multiple Pressures on the ecosystem. The current State of change occurs and does have impacts on the society.

The impacts can be accumulative effects and can last long or short time. The human responses, including different tools and approaches, must act towards these changes in managing the inland fish and fisheries to make them environmentally or ecologically sustainable.

2.2 Overview of the approach to the literature review

This thesis conducted a systematic literature review using different databases. The first phase of the literature search focused on a general treatment of freshwater ecosystem services and how researchers approach its assessment. The second addresses inland fisheries management under the context of climate change.

Systematic literature search

The first step involved a generic approach to the research area; articles which considered ecosystem services were sought after in this phase. The purpose of this generic approach was to get a broad view of the larger literature in which the study fits in. It was also to further justify why inland fisheries required attention within the ecosystem's literature. In the first phase, two databases were selected to conduct peer-reviewed literature search on climate change and freshwater ecosystem services assessment: Web of Science Core Collection and Scopus. The choice of the databases was determined after consultation with supervisors and library assistants at Grenfell Campus, MUN. The specific selection period is from 1990 to 2018. Articles published in 2018 were only included if they appeared in the database before April 2018. The researcher applied the search terms: 'freshwater ecosystem services assessment' OR 'ecosystem services' AND 'climate change'. Non-English language articles were excluded from the selection requirements. This was to ensure consistency and to ensure validity of materials included. Systematically applied criteria were used to identify the relevant literature. The following criteria were followed: (1) peer-reviewed English language journal articles; (2) articles published between 1990 and 2017; (3) articles addressing the impacts of changing climate or potential climate change effects on ecosystem services; (4) articles assessing climate change effects. The third review round involved screening the specific types of ecosystem services and articles genres in general. All articles were analyzed in detail and it was determined if they met the search criteria.

In phase two, four databases were selected to conduct the systematic literature review about climatic impacts on inland fisheries: Web of Science, Scopus, Google Scholar and The Federal Science Libraries. In Web of Science and Scopus, the specific selection period was from 1990 to April 2018. The researcher applied the search terms 'inland fisheries management' OR 'inland fisheries' OR 'freshwater fisheries' OR 'freshwater fisheries management' AND 'management' and 'climate change' in the Web of Science and Scopus. Google Scholar was added because of its ability to capture grey literature. Just as in the other databases, articles published in 2018 were only included if they appeared in the database before April 2018. Non-English language articles were excluded as noted for the first section of data collection. Several criteria were used to identify relevant literature related to climate change impacts on inland fisheries. The following criteria were established to conduct the review: (1) peer-reviewed English language articles; (2) articles published between 1990 and April 2018; (3) articles included the impacts of changing climate or the potential climate change effects; (4) articles closely related to inland fisheries and its management options or practices. The systematic literature review process applied can be found in Figure 2.1.

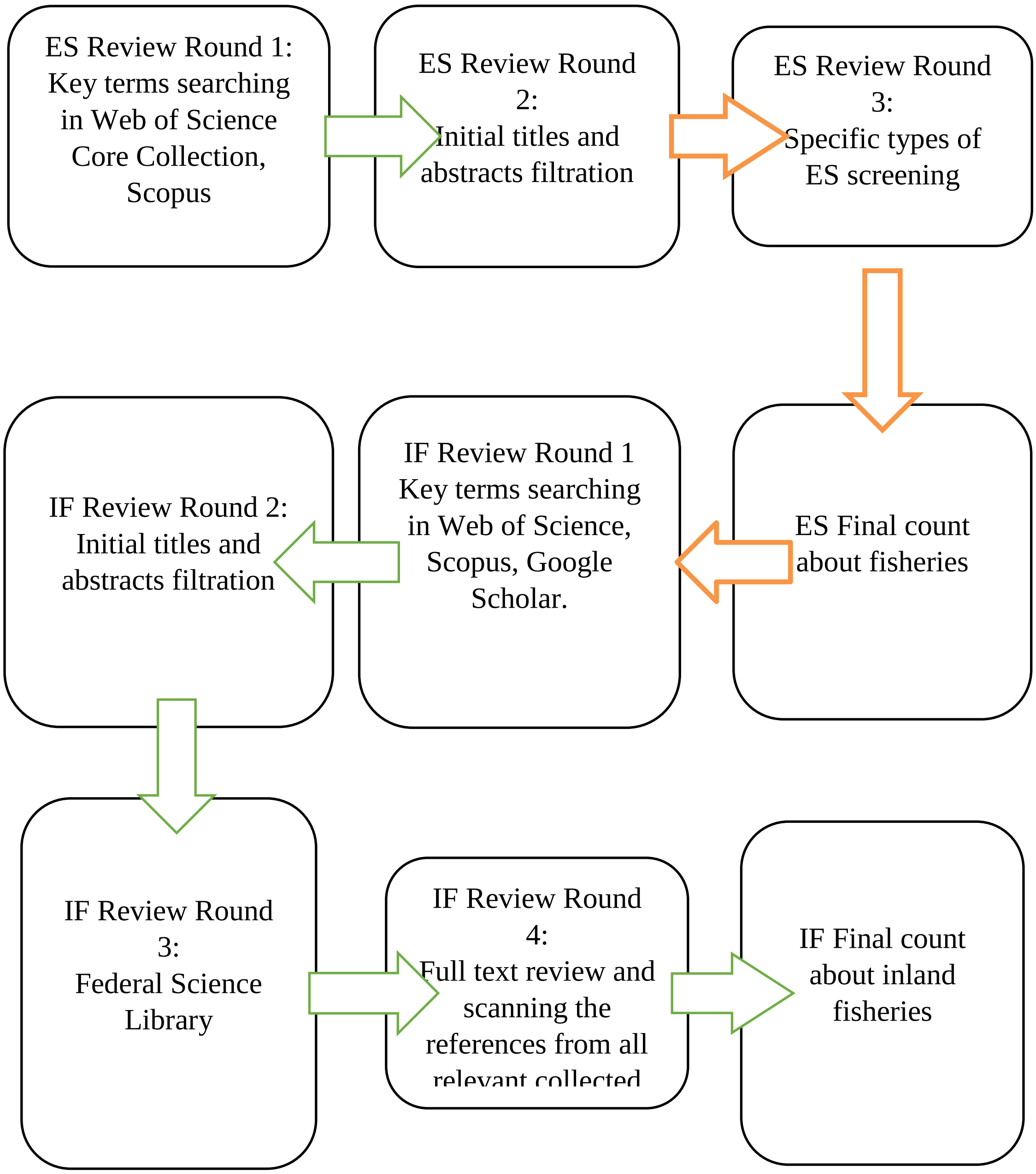

Figure 2.1 Literature review process

Source: Author's Construct (July 2018)

2.3 Data processing, presentation and analysis

The study aimed to systematically review literature on the impact of climate change on inland fisheries and how the phenomenon is incorporated into management decisions. Data were collected from online databases to assess the state of the literature and to understand how climate change is further incorporated higher up into decision making. Articles retrieved were carefully read for understanding. Pre-determined themes were then applied to seek information from the articles. Key statements were highlighted and copied into separate Word files, where they were later paraphrased to explain each theme. Data are presented using various forms of quantitative techniques and qualitative techniques. The univariate data analysis was employed to present basic descriptive characteristics of articles. Data were then organized and examined to generate frequency counts to compare among groups (for example, article distribution on place and year of publication). In analyzing qualitative data in this study, a thematic based content analysis was employed. Key themes were used as guide to extract information from articles while reading. Information was later grouped into the themes and explained using tables, graphs and descriptive writing.

Generally, data were analyzed through careful interpretation of findings. This involved the use of both observation and reasoning. In this sense, various patterns of findings derived from analyses were observed and with careful and thoughtful reasoning, the required analyses were made. This analysis was done making use of researcher’s own experience in the area of study as well as the available literature which aided in comparisons with the study’s findings.

Chapter 3 Results and discussions

3.1 Literature search

As mentioned earlier, the literature search was done in two phases with the first part aiming to position and justify the study within the broad literature on climate change and ecosystem services. From the first-round searches, 266 articles met the requirement in the Web of Science Core Collection, and 215 articles met the requirements from Scopus. The second round involved filtration which began with a review of the abstracts. The articles that were irrelevant to climate change impacts on freshwater ecosystem services were excluded. There were 66 articles that met the criteria in the Web of Science Core Collection and 52 articles qualified from Scopus. Following this review, 103 articles were selected from the second round of selection (See Table 3.1).

Table 3.1 Breakdown of selected articles for review

Types of ES	Science of Core Collection	Scopus	Total
Wetlands FES	5	1	6
Fisheries FES	3	1	4
Pure FES	12	10	22
Combination of FES and other ecosystem services	5	2	7
Review or synthesis	4	1	5
Widely generally described	3	1	4

The influence of forest on FES	2	1	3
More science models	12	5	17
Total	46	22	68

Source: Author's Construct (July 2018)

As the result of the first search, there were a limited number of articles which examined inland fisheries, especially regarding climate change. Therefore, more attention needed to be paid to the broad sector in relation to climate change. The second phase therefore built on the idea to undertake a tailored search based on inland fisheries. In the second phase, 997 articles appeared in the Web of Science after searching key terms, and 148 articles were from Scopus. In the Google Scholar, first, the author applied advanced searching by inputting key terms 'fisheries management', 'climate change' from the period of 1990 to 2018. About 89 articles were selected after excluding nine articles about marine fisheries. Second, the author searched the key words 'inland fisheries management', 'climate change' appearing anywhere in the articles. Around 17, 400 articles were showed in the results after applying searching. The researcher took the prior 300 articles as the data materials for review. So, all together 389 articles were finally collected from Google Scholar in the first round after key terms searching. There were 1534 articles selected in total from the first round, i.e. 997 from Web of Science; 148 from Scopus; 389 from Google Scholar.

The second round involved filtration, which began with a review of the titles and abstracts. The articles which did not meet the criteria were excluded. About 133 articles met the criteria in Web of Science, 65 articles from Scopus, 62 articles from Google Scholar from this round. One important reason for the result was high repetition of articles from Web of Science and Scopus. Following this review, 260 articles were selected from the second round of assessment. There was a concern that initially a low number of peer-reviewed articles met the criteria. Consequently, an additional third round of the review process was conducted.

The third round focused on Federal Science Libraries to target extra ‘grey’ literature, comprised of Canadian government reports and documents. It produced more than 305 articles related to climate change’s impacts in general from 1990 to 2018. However, only 8 articles were related to inland fisheries. The researcher used these results as a form of verification pointing to the paucity of articles dealing with climate change and inland fisheries. The fourth review round involved screening the full texts of all identified articles and scanning the references from them. All articles were analyzed in detail and it was determined if they met the search criteria. Finally, 99 articles were selected from these four databases. The systematic review process applied in the thesis has been conducted and the contents of the selected 99 articles were analyzed using the DPSIR framework. The analytic results about the context will be further described below.

3.2 Contextual information

The thesis aims to provide a systemic review of articles on inland fisheries impacted by climate change and the management and policy development about it. The systematic review revealed some patterns in the contextual information of the reviewed articles. Many contextual highlights can be derived from the review; however, for the purpose of this section, the years of publication and geographical scope of articles are described. The purpose of this approach is to understand how climate change incorporation into inland fisheries literature has developed across the globe over time. The two variables of years and geographical scope of the article can help evaluate the development of the field and help identify research gaps to position scientific priorities. The literature review disclosed important trends in publication patterns over time beginning in 1990 (Figure 3.1).

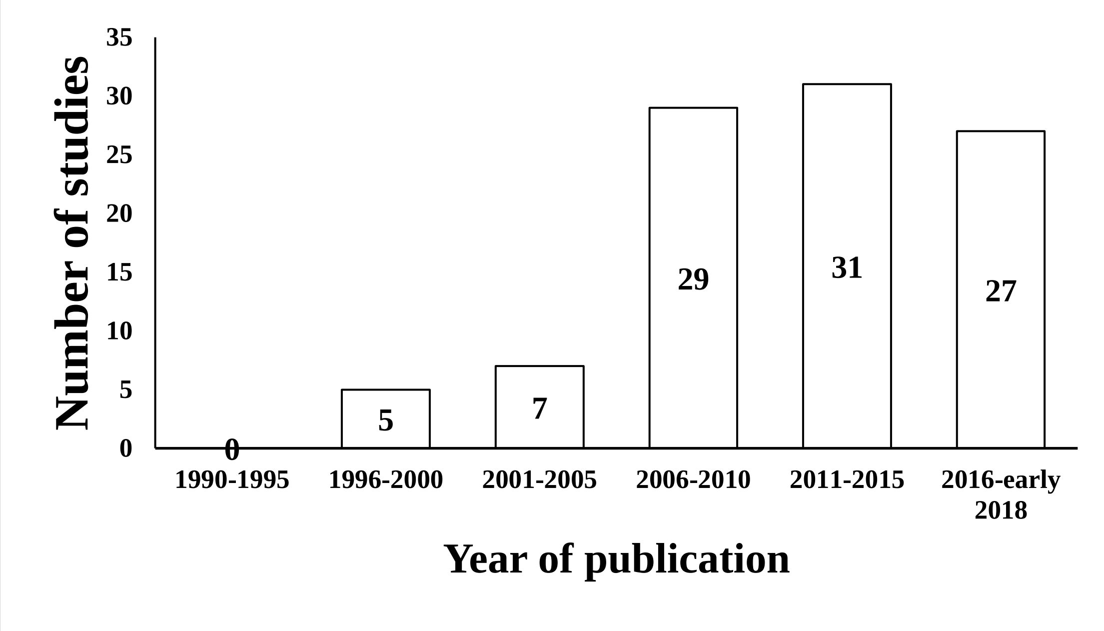

Figure 3.1 Year of publication of articles, 1990-2018

Source: Author's Construct (July 2018)

The date showed a general upward trend in the development of the research field, with the majority of articles emerging after 2006. There were virtually no relevant articles prior to 1995, but the situation changed abruptly in 2006. Interestingly, the growth in publications that occurred immediately after the turn of the millennium can be attributed to widespread attention to climate change beginning in 2000 (Xenopoulos et al., 2005; Brander, 2007; Whitfield et al., 2010; Hague & Patterson, 2014). Scholarly attention to climate change was particularly evident following the establishment of

Millennium Development Goals in 2000. The growth of articles from 2011, as in the last decade, reveals distinct academic attention to climate change impacts on freshwater fisheries as a means to facilitate policy actions in sustaining inland fisheries in the Anthropocene-the age of man (Malm & Hornborg, 2014). It must, however, be noted that despite an increase in academic attention to the issue in the last decade, the situation is not consistent across the globe.

A geographical scan of articles reveled a predisposition towards the developed world (North America). Spatial scale categories are classified by the seven continents of the world plus Arctic regions. The extent of research which takes a global scope to inland fisheries management is also included. North America accounts for the highest number of relevant studies with 33 articles, while South America and Arctic regions ranked the lowest, two of each (Figure 3.2).

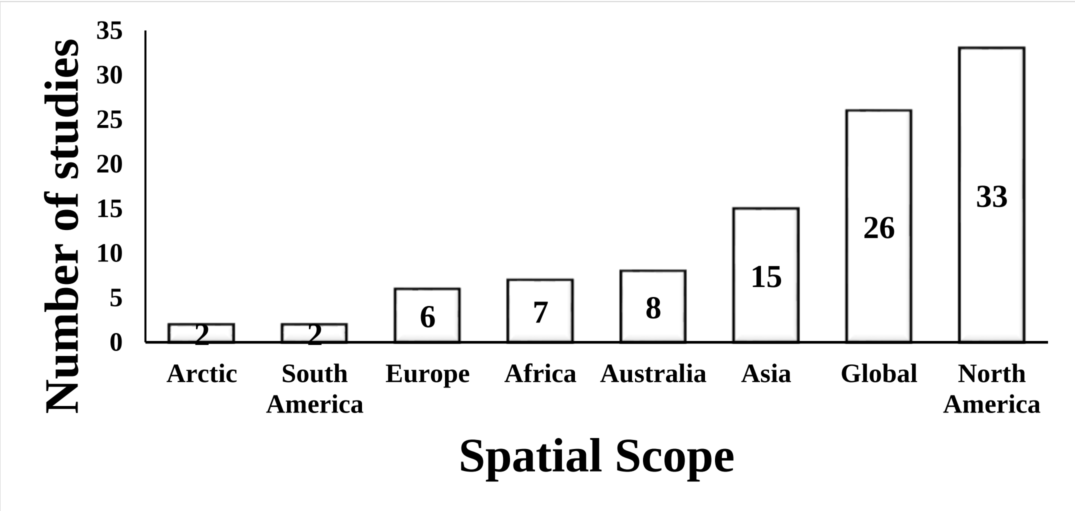

Figure 3.2 Spatial scope of reviewed articles

Source: Author's Construct (July 2018)

From Figure 3.2 there are significant variations in spatial scope of articles related to incorporation of climate change into inland fisheries. North America has the highest number of published works in the area, however it is unclear why this is the case. One reason that can be inferred is the extensive study of biodiversity in relation to fisheries in the North American context which has been reflected in earlier reviews of this nature (Hunt et al., 2016; Fussell et al., 2016; Blaber & Baletta, 2016). The researcher, however, acknowledges that this may also have been influenced by biases from search engine results based on location. That notwithstanding, the findings of this study therefore confirm the results of the geographical distribution of studies indicated in other reviews dealing with climate change and inland fisheries (Lynch et al., 2015; Gallowayet al., 2016; Hunt et al., 2016; Hansen et al., 2018).

3.3 DPSIR components from the perspective of inland fisheries management

The impact of climate change on natural resources, including inland fisheries, is enormous and complicated. Understanding the directions and scales of such impacts, and the policy implications are equally complex tasks for researchers and decision makers. The complexities of climate change-human systems interactions require careful analysis and more targeted approaches. As complex as climate change-human systems interactions may be, incorporating the phenomena into decision making could also prove daunting. This explains why researches have adopted established frameworks to understand the socio-ecological complexities. The DPSIR framework also allows further exploration of issues beyond human-nature interactions that may also have implications for resource management. Figure 3.3 and the discussion that follows employ the DPSIR framework to analyze inland fisheries management issues in the face of climate change, while highlighting non-climatic factors as well. Arrows represent cause-and-effect relationships among various components of the framework.

There are many stressors which are intertwined and interact with each other in the inland fisheries sector: some of them are very complicated and not easy to demonstrate in a simple way.

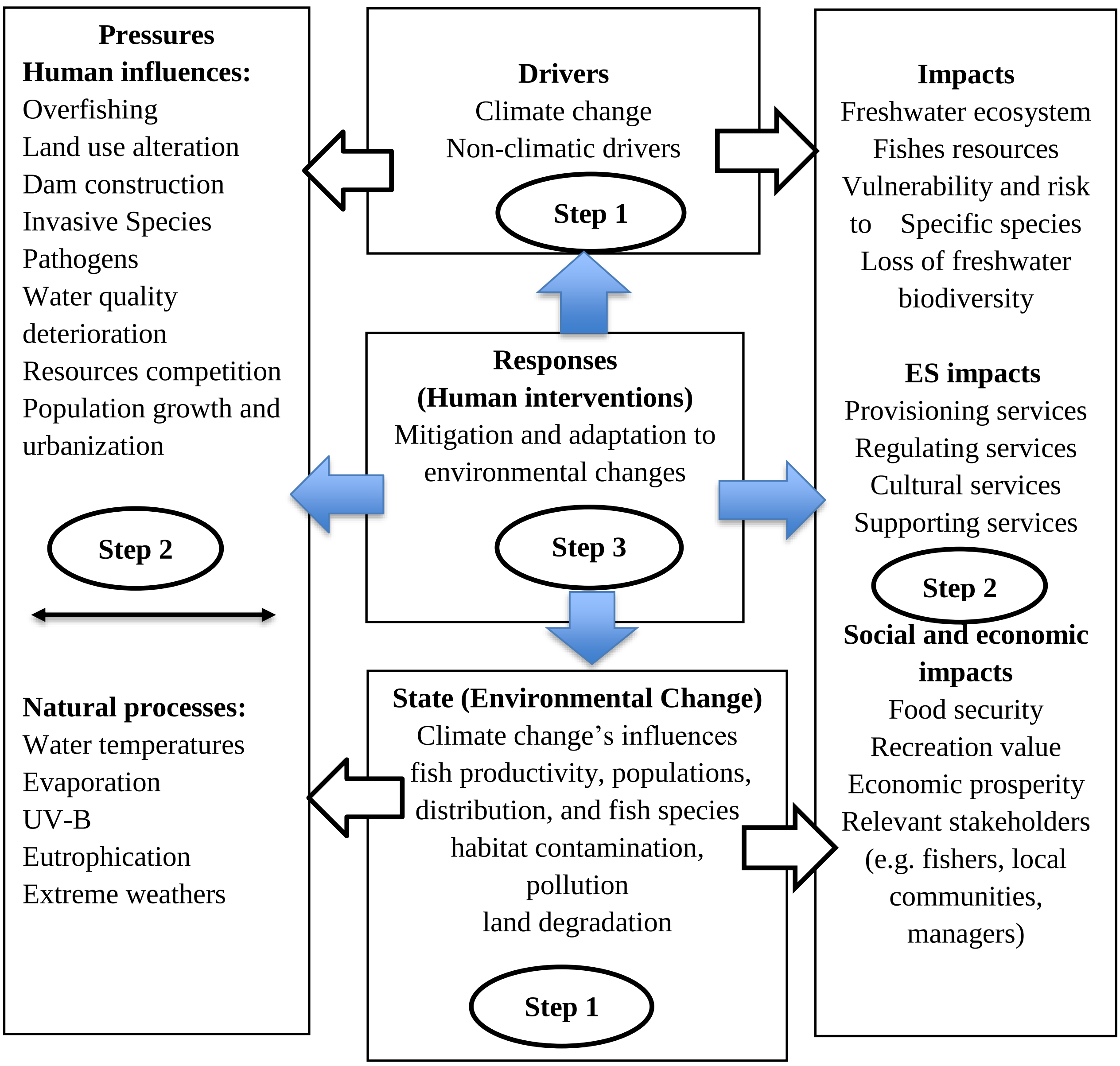

Figure 3.3 DPSIR analytical framework for integrated environmental assessment and reporting

Source: Adapted from UNEP (2007)

The above analytical framework (Figure 3.3) is based on the GEO reports based on Global Environment Outlook-4 and adapted from the UNEP (2007) to permit an integrated analysis of environmental trends and policies, through which we can understand current management practices and propose more effective and useful policy recommendations. The understanding of the current status of inland fisheries requires us to know the Drivers (Driving forces or indirect Drivers) and Pressures (direct Drivers) that influence different State variables. In this thesis, Drivers fall into two categories: climatic drives and non-climatic drivers (such as science and technological innovation, economic demands, etc.). The multiple general Drivers lead to more specific Pressures (e.g. overfishing, land use alteration, dam construction, invasive species, resources extraction, modifications of genetic organisms). These pressures cause changes of the state of the environment (climatic variables changing, loss and changes of fishes' biodiversity, habitat contamination and degradation, pollution, land degradation) and also changes caused by natural processes like air and water temperature changes. Changing environments impacts on the freshwater ecosystem itself include fish populations, fish distribution, fish productivity, biodiversity, habitat alteration and degradation, and land use changes. Importantly, the changing of ecological aspects can lead to profound changes in social, economic, and other human-related problems. Accordingly, societal responses to environmental change can affect the environment and the connected Drivers and Pressures. Different response groups seek to 'prevent, compensate, ameliorate or adapt to changes in the state of the environment' (Gabrielson & Bosch, 2003, P. 8). Two main societal responses groups can be identified with decision making according to decision patterns and scale: one is related to policy actions and another one to distinct responses from different levels of the society (from government, private sector or NGOs) represented by groups or individuals (Maxim et al., 2009). In the context of climate change, the responses can be divided into mitigation and adaptation. The mitigation part involves responses aiming at moderating impacts by enhancement or restoration. Adaptation includes responses aiming to help society develop adaptive capacity to environmental changes. Responses aim to restore or maintain the current State of the environment, or to aid to adapt to impacts by controlling drivers or pressures (Gabrielson & Bosch, 2003; Perrings, 2005). The combination of exposure to changes in states, the social adaptive capacity and sensitivity to changes determines the degree to which people are more vulnerable or resilient to changes. Responses sometimes may be regarded as negative drivers, because they target at guiding current popular trends to an opposite direction in consumption and production patterns (Smeets & Weterings, 1999). As such, the gap between drivers and response can be vague and changeable (Maxim et al., 2009). Multiple drivers can help dismantle the complex relationships between humans and environmental systems, and therefore, the DPSIR framework helps policy makers and relevant stakeholders better understand the issues faced by inland fisheries. It is also important to add uncertainty factors to the framework to avoid a linear cause-and-effect description of the problems. In the sections that follow, each of the analytical components (variables) of the framework is expanded to highlight their contextual applicability to inland fisheries management using the data from the review.

3.4 Drivers

Drivers are natural conditions or human activities which underpin environmental change. The Millennium Ecosystem Assessment (MA) report contends that drivers can be both natural and anthropogenic factors which directly or indirectly can lead to change in an ecosystem (MA, 2003). Historically, the term “drivers” is less often referred to as political and social factors but these should be taken into account in dealing with environmental problems (Maxim, Spangenberg & O’Connor, 2009). However, this thesis examines drivers from the perspective of both climatic and non-climatic factors.

With reference to climate change as a driver, various climate change attributes (e.g. temperature, precipitation, extreme weather events) have been mentioned in the literature, most of which include more than one attribute (Figure 3.4). About 24% of the articles mentioned climate change generally but the specific attributes are unknown. When articles appear specific, temperature is ranked as the first among the attributes, as discussed in 72 works. Precipitation change is also widely referred to, and ranked second, and this includes increasing or decreasing precipitation. Other attributes in combination with each other were also mentioned in these articles. Most of the articles mention more than four climate change attributes, which indicates the critical role of climate change in affecting the fisheries sector.

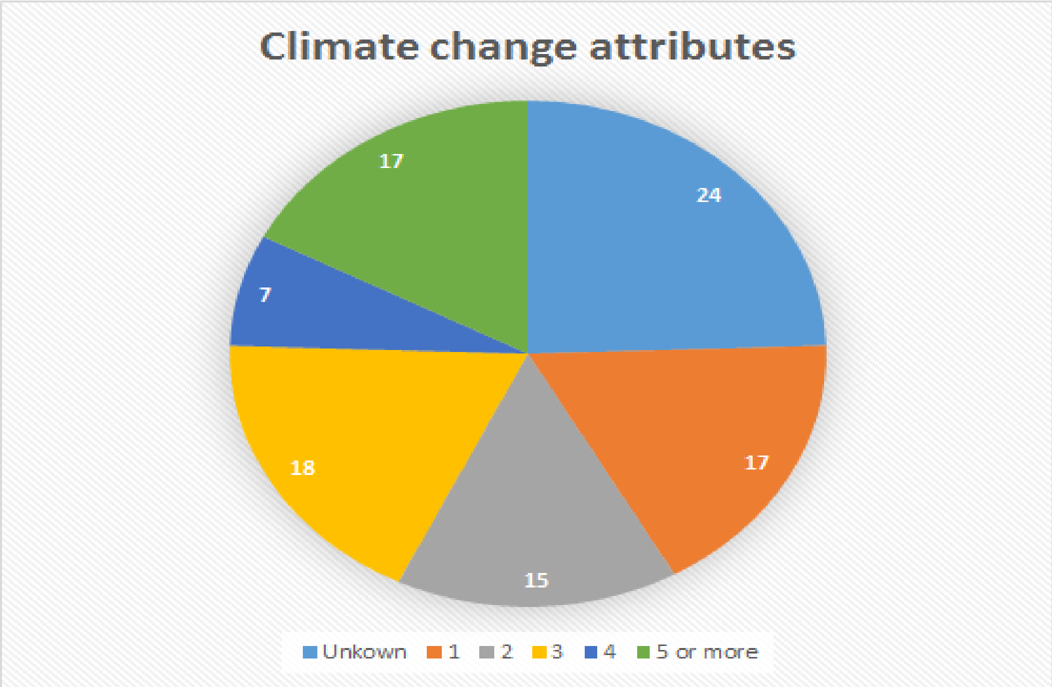

Figure 3.4 Number of climate change attributes discussed in articles

Source: Author's Construct (July 2018)

Climate change is imposing great pressures on inland aquatic ecosystems and may become a dominant factor influencing the sustainability of inland fisheries (Barange & Perry, 2009; Bates et al., 2008; Suuronen & Bartley, 2014). Warming water temperature has led to species range shifts in river fish communities along with decreasing survival rates and range contraction of cold-water species such as salmonids (IPCC, 2014, p. 295). Changing temperature regimes in the freshwater ecosystems may create opportunities for new aquatic habitats at higher latitudes for migratory species but range contraction posed threats to the long-term persistence of some fully aquatic species (IPCC, 2014, p. 295). The evidence of climate change impacts on fisheries has accumulated, but it is suggested that climate change itself as a driver for inland fisheries management has been underestimated and neglected for a long time (Taylor et al., 2016).

In much of the literature, climate change is a major driver. However, there is more to the issue of inland fisheries management than just climate change. Many studies have mentioned other drivers, including economic development, demographic changes, technology and innovation development, and internal fisheries management practices (Welcomme et al., 2010). Since climate change is the focus of this research, discussion of these non-climatic drivers is limited. It must, however, be noted that climatic and non-climatic drivers both impact freshwater ecosystems and influence the management of inland fisheries across the globe.

3.5 Pressures

Pressures are caused by driving forces and can also be influenced by the societal responses to a particular environmental problem (Kristensen, 2004). Pressures are largely anthropogenic inclinations that lead to environmental change (Impacts). There are multiple stressors contributing to inland fisheries management under climate change conditions. The evidences of Pressures from this review can be classified into four categories: environmental, social, economic and political pressures, which are distinct but closely related (Table 3.2). This classification also matches the sustainable spheres for inland fisheries decision making (Lynch, Varela-Acevedo & Taylor, 2015).

Table 3.2 Pressures to Climate Change and Inland Fisheries Management

Categories	Evidences from the review

Environmental pressures	climate variability, climate change, species invasion, land use change
Social pressures	overfishing or overharvesting, agriculture erosion, deforestation, developing trends in pastime activities, population growth and urbanization, industrial water pollution, dam's construction, infrastructure development, water abstraction
Economic pressures	social interests, global economic conditions, economic market changes, technology and innovation, domestic and international trade, fuel costs
Political pressures	lack of governance (illegal fishing) or improper fisheries management, governance and political stability, water quality regulation, foreign aid, demands for the conservation of freshwater amenity and biodiversity

Source: Author's Construct (July 2018)

From the table above, many social, economic, environmental, and political pressures have been mentioned in the literature (Whitney et al., 2016; Whitney, 2016). From the literature, climate change features as a major pressure to inland fisheries. Other environmental pressures including climate variability and invasive species have also been linked to climate change in the literature (for example, Vass, Das, Srivastava, & Dey, 2009; Whitney, 2016). Overfishing, foreign species invasion, pollution and other anthropogenic factors are some of the notable pressures emphasized in the articles. The diversity of pressures shown in research further highlights the complexities involved in inland fisheries management, at a time when human induced climate change appears to be increasing.

4.6 State

The review has shown that the current status of inland fisheries and their management under climate change conditions are threatened by multiple stressors, as mentioned above. For example, water pollution, water and land resources competition cause a degradation in water quality and quantity, which can lead to a decline in fish productivity, fish populations, fish distribution and fish species habitat. In addition, fishing activities have negative impacts on fish abundance, their sizes, and biodiversity, which in turn makes them more sensitive to climate change because of the changes of inner fish age structure and geographic distribution (Brander, 2007), creating a strong synergic effect between climate and fishing.

Globally, fish suffered a decline of 76% over the past 40 years (WWF, 2014) primarily through damage to freshwater habitats (Fausch et al., 2002). Indeed, freshwater fish are the most threatened and endangered taxa among freshwater vertebrates globally (Collen et al., 2014). One result of this decline is higher dependency on that resource by the aquaculture industry. It is expected that aquaculture practices will have to increase to meet the demand for food in the future as the result of increasing human population and decreasing capture fisheries (De Silva & Soto, 2009). However, like in natural systems, climatic influences can result in physiological pressure on cultured stocks and affect their productivity in aquaculture fisheries (Karmakar et al., 2018). There is also a high tendency for cultured fishes to suffer from disease and other related risks, leading to loss of profits for farmers (Karmakar et al., 2018).

Studies show that various stressors or pressures accumulate together, and they are unlikely to appear separately, and the synergistic effects give rise to complex and unpredictable 'ecological surprises' to the current state (Jackson et al., 2016; Koehn et al., 2011; Williams & Jackson, 2007). For example, because of climate variability, fishing activities, and other human caused environmental problems and combined stresses, up to the present, the commercial fish populations have not recovered in Alaska (Ward et al., 2017). Another example is that River Indus delta' s fish stocks decline caused by coastal erosion, has become a serious problem in the demersal (including penaeid catch decline) fish stock in Pakistan, mainly because of interactions among climate change and human interventions (Kidwai et al., 2016). The literature review disclosed that in general anthropogenic activities can lead to changes in ocean and estuarine conditions, and in turn intensify the intra- and inter-specific competition between freshwater and marine ecosystems (Maas-Hebner et al., 2016). The fast pace of degrading natural resources, habitat loss and economic loss are all alarming for fisheries managers who continue to advocate more suitable and useful policies to regulate freshwater and related fisheries resources.

4.7 Impact

Arnason (2003) proposed that climate change has direct (e.g. changing the fish accessibility to fishermen) and indirect (e.g. altering fish products and fisheries inputs prices) impacts on fisheries. Climate changes also have influences on fish production quantities and cost of fish and related ecosystem services. Aquatic ecosystems provide large amount of goods and services and inland fisheries are especially important for not only food security but also for providing numerous other valuable services (Welcomme, 2011; Béné et al., 2016). The ecosystem services provided by inland fisheries are displayed below (Table 3.3).

Table 3.3 Ecosystem services provided by inland fisheries

Setting	Commercial inland fisheries	Recreational inland fisheries	Artisanal fisheries (Small Scale Fisheries)	Freshwater aquaculture
ES derived	Human food, other animals or uses, economic value	Human food, cultural services, recreational services, economic value	Human food, livelihoods, cultural services	Human food, economic value
Location	Global	More in industrialized countries	More in developing countries	More in developing countries
Main species	Pacific thread herring, Atlantic salmon, rainbow trout	Cyprinids, black bass, white Walleye	Tilapia, common carp	Halibut, salmon, trout

Source: Author's Construct (July 2018)

Inland fisheries mostly focus on recreational value rather than food production in industrialized countries such as in South America (Welcomme et al., 2010). The resources are more exploited in the African and Asian countries of the world. There are some positive impacts of climate change, such as new species, new markets, and enhancement of fish production in tropical and subtropical areas (De Siva & Soto, 2009; Paukert et al., 2017; Karmakar et al., 2018). However, the general global impacts of climate change and other drivers on inland fishes and fisheries are its negative impacts on food security, livelihoods (fishers or communities), economic prosperity (level of poverty, economic loss, less recreation value), environment (e.g. habitat), distribution and productivity of fish species (fish population), freshwater biodiversity (removal of species, or species loss), vulnerability and risks, which greatly impede social and economic development. These impacts are discussed in more detail below.

3.7.1 Less food security

In many areas of the world, food security is listed as one of the most important challenges, driven largely by climate change, population growth, and decentralization (Béné et al., 2016). Fisheries play an integral role in global food security (Paukert et al., 2017; McIntyre et al., 2016; Lynch et al., 2015). About 158 million people depend on freshwater fish as their primary animal protein source worldwide (FAO, 2010). Inland fisheries for people in poor regions are especially important and prominent compared with marine fisheries because of the urgent and basic needs of undernourished populations and possible underinvestment in sectors including fisheries. Fish provide a well-balanced supply of compounding minerals and vitamins D and B, in addition to protein (Speedy, 2003); therefore, they can provide human beings a means to secure adequate food resources especially in low income and food deficient countries (Welcomme, 2008; Welcomme et al., 2010; Kawarazuka & Béné, 2011). Because of the significant amount of protein provided, the affordable low cost and easiness of accessibility, millions of people around the world in developing countries heavily rely on inland fisheries resources. For example, people of Cambodia consider fish as the second most significant staple food after rice in Cambodia (van Zalinge, 2002). The fact that the areas where there is lower food security have more fruitful inland fisheries production shows that inland fisheries can provide easily accessible protein and food sources (McIntyre et al., 2016) and this speaks to their significance in ensuring food security. For example, a small palm sized fish can meet a kid's daily needs of zinc and iron from Mekong River (Taylor et al., 2016), which is beneficial for children' cognitive development and also for adults' wellbeing. Unfortunately, the important role of inland fisheries in meeting food security is greatly underestimated (Welcomme et al., 2010). SSF's contribution to food for rural poor areas is highly underscored because there is no record about the quantity consumed and economic values (Andrew et al., 2007; Bartley et al., 2015), but obviously, they provide a main protein source for many nutritionally vulnerable people and are very important in global food security (Lynch, Varela-Acevedo & Taylor, 2015). Inland fisheries can also be a food source for other animals, for example, they can be feed source for livestock or aquaculture operations. Progressively, inland fisheries have played a key role in sustaining aquaculture operations, in an effort to push forward global food security efforts. Accordingly, there is a spatial coincidence between productive freshwater fisheries and low food security, verifying the significant role of inland waters played in providing low cost protein and local food sources (McIntyre et al., 2016).

3.7.2 Economic prosperity

Except for providing an affordable food source, ensuring local food security, inland fisheries also make great contributions to the world's economies. These fisheries represent a strong economic base for many countries. Inland capture fisheries have additional market value and economic value such as providing employment and leisure opportunities and generating income and experiential activities like tourism (Holmlund & Hammer, 1999; Lynch et al., 2015). Their production process is not only related to the catching, harvesting and farming activities but also involves processing and marketing, which can be regarded as secondary services activities (Brummett et al., 2007 Welcomme et al., 2010). Fishing is a livelihood and throughout the world makes a strong contribution to life quality; it is therefore economically driven regardless of its scale (Valdimarsson & Metzner, 2011). Climate change has big influences on both inland capture fisheries and aquaculture production as well as on the global fish markets connected to them. Impacted fisheries may cause developed countries to suffer economic losses and make it harder for developing countries to meet food demand (Ficke et al., 2007). In the fisheries sector, recreational fisheries are of great economic value in addition to commercial fisheries' contribution to GDP of many countries (Allen, Southwick & Howlett, 2013). SSF's economic value is however underestimated because they do not always enter into the market and are normally consumed by local communities or fishing families, the outputs are confined in local scope (FAO and World Fish Center, 2008). Consequently, economic statistics for small-scale inland fisheries are limited and there may be no record or information to indicate the net worth of the fisheries market and its value to national or regional economies (Andrew et al., 2007; Bartley et al., 2015).

3.7.3 Loss of livelihoods

Inland water bodies are inhabited by various species. Many fisher communities also live adjacent and depend on these water bodies; thus, the livelihoods of local communities are likely to be affected because inland fisheries are very important as a food source and more broadly to local economies. Understandably, because of sea level rise and changes in salinity, climate change is expected to first affect local communities near rivers or estuaries or nearshore coastal waters. Also, for fishers who rely on fishing for their livelihood, the impact of climate change is obvious because of influence on habitats, fishing seasons and fish abundance (Hunt et al., 2016). However, these significant impacts on livelihoods have been ignored in climate change adaptation policies even for marine fisheries management (Badjeck et al., 2010).

3.7.4 Environmental degradation

Environmental degradation is a crucial factor contributing to the current state of freshwater fisheries. Among the 133 reported countries with inland capture fisheries production, only 39 of them have shown positive results towards environmental sustainability capacity. More than half of these countries are highly dependent on fisheries production (FAO, 2003). Hence, the sustainability of inland fisheries is ostensibly affected and threatened. Habitat alteration, fragmentation, and habitat loss are among the most serious factors responsible for environmental degradation. The important role habitat quality and quantity play in maintaining fisheries resources should not be underestimated; loss of habitat may affect inland fisheries resources more than the exploitation rates (Arlinghaus et al., 2002; FAO, 2010). One known factor affecting habitat quality is increasing temperatures and productivity caused by climate change that can be harmful to salmonid habitat quality in shallower and productive lakes (Blair et al., 2013). Moreover, inland waters are usually located near human activity areas and they are experiencing cascading effects from terrestrial systems and disturbances from upstream watersheds. Consequently, they are highly vulnerable to land use changes and climate change (Lynch et al., 2015). In general, climate change has the potential to augment the speed of altering land use by modifying the aquatic system (Jones et al., 2006).

3.7.5 Less productivity of fish

Fish species losses and population reductions occur worldwide. For example, fish catches in the world's largest inland fisheries catchment, the Mekong River, have fallen dramatically following land use changes and river regulations (Dudgeon, 2000; Ferguson et al., 2011). There are still about 200 more dams under construction or planned in the Mekong river posing great pressure for fish migrations as well as food security because the catchment provides local people about 70% of the protein source (Osborne, 2004). The same situation is cited for rivers in USA, leading to almost extinction of diadromous species with declining rates of 95% to 99% because of dam building and overfishing and habitat changes (Brown et al., 2013). The fish habitat loss in many areas in Canada also result in less fish productivity (Quigley & Harper, 2006). For example, Edge et al., (2017) used five watersheds around the Toronto area to show how human activities have led to loss of biodiversity in the region. And in fact, the factor of changing climate has also been noted to be aggregating the situation (Chu, Mandrak & Minns, 2014).

3.7.6 Distribution and biodiversity loss

Climate change and other anthropogenic impacts make freshwater biodiversity degrade faster than marine or terrestrial biodiversity (Alcamo et al., 2003; Dudgeon et al., 2006; Jenkins, 2003). Strong evidences show that climate change is exacerbating the speed of decline for many freshwater species, especially in arid areas or Mediterranean climates (Moyle et al., 2013). Freshwater fish are considered especially vulnerable to environmental changes, because of their dispersal ability, besides being greatly constrained by the river network structure (Grant et al., 2007), and they are further limited by artificial barriers (Branco et al., 2014). Factors that are intrinsic to species, such as physiological traits, may also be subjected to the potential effects of climate change on fish. Climate alterations can lead to changes in growth, survival, reproduction rates, or in responses to changes at other trophic levels (Beaugrand et al., 2002: 2003). In fact, recent studies have demonstrated a significant effect of species traits on the variability of the observed range shifting trends on stream fishes under climate change (e.g. Alofs et al., 2014).

Endemic species or those with limited ranges are naturally prone to extinction (Brown & Kodric-Brown, 1977; Stacey & Taper, 1992; Hanski, 1994; Angermeier, 1995). Therefore, another possible effect of climate change is the loss of biodiversity through the extinction of specialized or endemic fish species. It is difficult to quantify this loss in financial terms, but there is some evidence that people are willing to pay to preserve native fish species (Nishizawa et al., 2006), even those that are not commercially or recreationally exploited (Loomis & White, 1996). Furthermore, it can be argued that biodiversity has intrinsic and ecological value and should be preserved whenever possible.

3.8 Responses

As to response to the drivers and pressures and current status of inland fisheries, management options for policy makers are needed to consider comprehensive factors including natural conditions, societal elements, economics, as well as scientific uncertainties (Lynch, Varela-Acevedo & Taylor, 2015). Responses sometimes can be seen as negative drivers (Smeets & Weterings, 1999). For instance, if policies aim at managing climate change impacts on the inland fisheries, they can be regarded as responses. Some policies or recommendations may not fully consider climate change aspects or if there is inadequate regulatory attention, they can also be considered as drivers or pressures. The literature has highlighted many responses to the drivers of climate change in the inland fisheries sector. More than nine major themes are derived in this thesis from the responses (existing and proposed) in inland fisheries management under the context of climate change: conservation approaches, water management approaches, proactive approaches, modelling approaches, adaptive approaches, resilient approaches, cross-sectoral approaches (stakeholders' involvement), monitoring response, and other responses. Table 3.4 outlines these themes and the specific responses under each of them and highlights responses to climate change.

Table 3.4 Responses to climate change and other drivers' impacts on inland fishes and fisheries

Approaches	Specific response	References
1.Conservation	conservation introduction	Galloway et al., 2016
	biodiversity conservation management design	Cohen et al., 2016
	genetic diversity among stocks and habitat conservation	Uppanunchai et al., 2015; Bryant, 2009
	fish conservation management (involving stakeholders)	Collares-Pereira & Cowx, 2004
	the freshwater biodiversity conservation	Chu et al., 2015; Crook et al., 2010; Heino et al., 2009
	habitat conservation	Whitfield et al., 2010; Bryant, 2009
2.Water management	integrated watershed management strategy	Vass et al., 2009; Groll et al., 2016
	management of freshwater systems	Jackson et al., 2016
	improving water management and other features of hatchery operations	Uppanunchai et al., 2015
	inter-jurisdictional integration development	Poesch et al., 2016
	integrated assessments of the potential impacts and viable response options for alternative climate futures	Meyer et al., 1999

	increased research and a national water state	Schindler, 2001
	reductions in water consumption	Xenopoulos et al., 2005
3. Precaution	proactive management	Ficke et al., 2007
	applying the precautionary principle	Hughes et al., 2000
	proactive and mitigation for resilience	Morrongiello et al., 2011
	precautionary management	Cochrane et al., 2009
4. Modelling	mechanistic modelling approaches	Fussell et al., 2016
	appropriate and effective models	Koehn, 2011; Hague & Patterson, 2014
	long-term studies and the development of predictive models	Elliott et al., 2010
	development of models linking climate variability and ecological processes	Meyer et al., 1999
	a more process-based approach especially using climate models	Hobday & Lough, 2011
5. Adaptation	adaptive management	Maas-Hebner et al., 2016; Hughes et al., 2000; Lynch et al., 2015
	adaptation options	Uppanunchai et al., 2015; Das, 2013
	adaptation strategies development	Koehn, 2011; Das & Sharma, 2010
	development of adaptive capacity	Natugonza et al., 2016
	capacity building among the community various adaptation options	Karmakar et al., 2018
	building adaptive capacity	Allision et al., 2009; Chu et al., 2005; Daw et al., 2009; Hyatt et al 2003
	enhance the adaptive capacities of the livelihoods	Jayasinghe & Niroshana, 2016
	capacity-building would be enhanced	Sam Ath et al. 2013
	vulnerability and adaptation strategies	Das & Sharma, 2010
	adaptive and ecosystem-based approach	Poesch et al., 2016; Lynch et al., 2016
	ecosystem approach in resource management with a sustainable approach	Karmakar et al., 2018
6. Resilience	developing resilient systems	Paukert et al., 2016
	maximizing resilience to the effects of climate change	Wainwright et al., 2013
	resilience-based approach	Allison et al., 2007
	resilience-building measures	Pittock, Hansen & Abell, 2008
7.Partnership building	cross-sectoral solutions	Das et al., 2013

	engage more effectively with other stakeholders	Graaves & Maule, 2014; Pauket et al. 2017
	participatory activities	Alho et al., 2015
	integrating all actors transboundary approaches	Midway et al., 2016
	cross-sectoral interventions	Priti Sanga et al., 2014
	intra-sectoral management that builds resilience and reduces vulnerability	Andrew et al., 2007
	mitigation measures (require cooperation among all stakeholders) and management practices	Karmakar et al., 2018
	integrated management in order to acknowledge all interests involved	Groll, et al., 2016
8. Monitoring	long-term monitoring	Paukert et al., 2016
	adaptive monitoring	Fussell et al., 2016
	improving monitoring and information systems	Uppanunchai et al., 2015
	improvements in both ecological monitoring and modeling	Meyer et al., 1999
9. Others	ecological and human responses to climate change	Strayer et al., 2010
	stock-specific responses	Martins et al., 2011
	encourage rational and deliberate planning of engineering responses to climate change	Strayer et al., 2010
	physiological approaches	Reist et al. 2006
	empirical approaches	Reist et al. 2006
	distributional approaches	Reist et al. 2006
	integration of local knowledge	Sam Ath et al. 2013
	reducing fishing mortality	Brander, 2007
	distinct management approaches	Condie et al., 2012
	intervention options	Béné & Friend, 2009; Morrongiello et al., 2011

Source: Author’s Construct (July 2018)

These responses aim at ensuring successful management of inland fisheries under a changing climate. In the sections that follow, the responses are discussed with a view to incorporating climate change into inland fisheries management.

3.8.1 Conservation

Fisheries conservation is regarded as a very important part of inland fisheries management because the loss of freshwater fish biodiversity is a pressing issue exacerbated by climate change. In many countries, there is established legislation to conserve freshwater stocks. For example, acts such as the Water Framework Directive in Europe and the National Water Act in South Africa address ecological integrity or quality, aiming to use integrative methods to define ecological quality by incorporating abiotic and biotic components that make ecological status assessment possible (Borja et al., 2008). A number of specific species issues are also addressed by fish stocks conservation legislation. For example, the USA Endangered Species Act was adopted to protect endangered and threatened species (Angermeier & Williams, 1994). Even though many countries have taken actions and set up institutions to protect fisheries biodiversity, the concept of fisheries biodiversity conservation has only recently gained global consensus (Crivelli, 2002; Kirchhofer, 2002). Climate change's role in threatening freshwater biodiversity has been identified and it is likely to strongly affect freshwater biodiversity in the future (Heino et al., 2009, Poff et al., 2009), but human responses to climate change, including fish conservation, could give rise to larger negative effects (Strayer & Dudgeon, 2010). There are additional problems arising in fisheries conservation efforts, such as a lack of public awareness, insufficient baseline information, and failure to connect fisheries conservation to other management options (Cowx & Collares-Pereira, 2004). Moreover, many institutions do not have enough resources to enforce legislation and carry out sound conservation plans. Generally, traditional conservation measures and management practices can help sustain the fisheries, but in many cases, they may be insufficient (Hollowed et al., 2013).

3.8.2 Water management

Inland freshwater ecosystems are being altered by a multitude of factors including changing climate, pollution, and invasive species (Carpenter et al., 2011) which are conversely affecting fisheries, making it more difficult for managers to reflect on past experience and forecast future capability (Paukert et al., 2016). Water abstraction and pollution are great pressures for the inland fisheries sector and need human responses. These new challenges highlighted by climate change call for more effective management strategies and innovative actions to better regulate inland fisheries sector and to ensure resources are more sustainable. Many articles recommend integrated water management approaches including employing mitigation technologies and building their cost into investment plans for water management infrastructure (Brummett et al., 2013; Vass et al., 2009; Groll et al., 2016). Such steps would improve the cost-benefit ratio and the fisheries valuation. Xenopoulos et al. (Xenopoulos et al., 2005) even suggest reducing water consumption to prevent inland fishes from extinction. However, because some current policies unfortunately generally tackle water management for purposes of irrigation, flooding, and other uses with less consideration on fisheries sustainability (Agnew et al., 2009), inland fisheries will still continue to compete with industrial, agricultural and other sectors for freshwater resources. Combined with climate change's influence, those stressors require integrated water resources management to manage fisheries better (Das et al., 2013; Hughes & Morley, 2000).

3.8.3 Proactive approaches

At a time when overexploitation of significant fish stocks, major economic loss, and international management conflicts increase, unreported and unregulated problems, and unsustainable fishing practices continue to occur. This added complication of climate change impacts is of great concern to inland fisheries management. Precautionary measures have been proposed (FAO, 1996; FAO, 1997) to solve the threatening fisheries issues and achieve long-term sustainable fisheries around the world. The precautionary approach for fisheries management aims to 'achieve the long-term sustainable use of fisheries resources by actively seeking ways to optimise the benefits derived from resources available' (Cochrane, 2002, p231). In the climate literature, an action to overcome climate change can either be adaptation or mitigation. Mitigation is a proactive approach because it turns to work to prevent the phenomena. However, adaptation is largely reactive though it can be used proactively at certain times (IPCC, 2007). The precautionary approach acknowledges that changes in aquatic systems are difficult to reverse in a short period and are susceptible to variations in environmental and social values (FAO, 1996). Hence, there is the need to avoid activities when there is not full knowledge of their impacts on climate. This baseline thought of the precautionary approach makes it proactive in preventing climate change. Although difficult, preparing beforehand to prevent further loss of inland fisheries is also very important and precautionary management can be instrumental in successfully managing inland fisheries and aquaculture (Cochrane et al., 2009). A precautionary approach can also be used for managing water resources (Hughes & Morley, 2000) to keep a balance between protecting aquatic ecosystems and economic prosperity.

3.8.4 Modelling

Compared with global changes, regional climate changes are more difficult to predict because small fluctuations patterns of climate may cause long-term and deeper consequences for some regions (Mooij et al., 2005). A number of works propose that models should be more accurately established and validated, especially in watersheds for regional and national fisheries management (Meyer et al., 1999; Elliott et al., 2010). Temperature forecast models or climate change scenarios for fisheries management are essential because of the important role of temperature as a result of climate change and its influence on fish habitats (Graaves & Maule, 2014; Hague & Patterson, 2014). Generally, inland fisheries and aquaculture are more easily influenced by thermal regimes which can be modified by climate change (Karmakar et al., 2018). Development of models should also be based on scientific information and data from comprehensive sources (Koehn et al., 2011), including various factors of current Drivers and Pressures to make policy decision-making more effective. Evaluations for model performance under different conditions and management goals should also be emphasized (Hague & Patterson, 2014).

3.8.5 Adaptation and resilience

Adaptive options in inland fisheries management ranked highest in all the articles reviewed, because the impacts of climate change are globally distributed. Consequently, diverse problems exist and need to be solved. The management of fisheries will be difficult to address due to the trajectory of climate change, so adaptation is a necessity if the resource is to be successfully managed under a changing climate (Paukert et al., 2016). Because resilience and adaptability are often considered jointly together in most of the literature dealing with fisheries management, this thesis will briefly discuss them. The influences of climate change on water availability and interactions among ecological, social and economic aspects are hard to project (De Silva & Soto, 2009; Daw, Adger, Brown & Badjeck, 2009). The adaptive capacity of relevant individuals, aquatic ecosystems, and their sensitivity to changes is important for coping with vulnerability. Developing countries are particularly inclined to suffer most from climate change's negative impacts because fisheries are a very important economic and climate-sensitive sector (IPCC, 2001b). Marginalized people or poorer countries are likely to be more vulnerable and get less benefits from climatic impacts compared to others, because of insufficiency of measures taken (Harrold et al., 2002). Therefore, capacity building is essential in many circumstances. For example, promoting general education and targeting initiatives beyond the fisheries sector to raise the awareness of climate change impacts on inland fisheries is one way to build stronger capacity (Cochrane, De Young, Soto & Bahri, 2009). The negative impacts of climate change influence the adaptive capacities, increasing vulnerability and reducing resilience for these changes.

Adaptive strategies in biological terms need to be robust. Unpredictable situations often occur and preparation for extreme conditions and surprises are needed (Wilby et al., 2010). Adaptive measures in inland fisheries management during the past few years include watershed protection to prevent and reduce nutrients entering to rivers and lakes, resulting in minimizing dissolved oxygen levels (Franklin, 2014). New harvest regulations have also been enacted to ensure the diversity of populations (Hansen et al., 2015), and to manage resilience actions (Paukert et al., 2016).

Fisheries enhancements have also been widely used in inland fisheries and coastal fisheries management regimes to restore or enhance fisheries in natural ecosystems. Measures like construction of brush parks for fish aggregation or translocations of juveniles, have existed for centuries (Welcomme, 2002). Fisheries enhancements management practices are still expanding due to rapid development of aquaculture technologies (Lorenzen, 2014). Enhancement approaches are useful in assisted migration of freshwater species in climate change adaptation (Rahel et al., 2008). In some instances, for example in Zambia co-management has also been introduced for human-fisheries conflict mitigation (Ndhlovu et al., 2017). Another strategy employed as an adaptive feature is using an ecosystem approach to fisheries in inland fisheries management, which is a holistic approach aiming to balance a variety of goals (FAO, 2003). It represents a transition from a conventional fragmented decision-making process to an integrated approach for natural resources management dealing with various ecological and human sustainable dimensions in resources planning and policymaking process. An ecosystem approach is needed and beneficial because climate change is often intertwined with other threats and the effects are comprehensive and complex (Poesch et al., 2016; Lynch et al., 2016; Karmakar et al., 2018).

3.8.6 Partnership building

Fisheries management strategies often involve various stakeholders at different spatial scales and their involvement is often integrated with various other approaches. Dealing with different stakeholders to get the policy well placed and mediating their contradictions and even getting them to collaborate with each other is not an easy task.

For example, challenges often appear in implementing policies such as land use and long-term monitoring processes for resilient systems (Paukert et al., 2016).

Climatic induced global impacts occur at a large scale, therefore, there is a need for new partnerships and cooperation among government, fisheries, NGOs and other community-based organizations or international-level stakeholders. The complex interactions among stressors need to be better understood taking into account scale and complex interactions. This requires strong co-operative governance to improve management practices involving both national and local stakeholders (Van der Zaag, 2005). It is very important that ecosystem-based approaches, integrated assessment and management approaches be incorporated in the management procedures (Lynch, Varela-Acevedo & Taylor., 2015; Groll et al., 2016; Karmakar et al., 2018). Integrating different stakeholders can also be a challenge and will be explained in detail in a later section (see Section 3.11).

3.8.7 Monitoring

Since there are many uncertainties associated with climate change impact, monitoring is essential to keep track of climate change effects in freshwater ecosystems (Jimenez Cisneros et al., 2014). Fishery managers depend largely on monitoring programs for both spatial and temporal differences. Metrics are needed to assess the status of fisheries, fish populations and angler satisfaction (Paukert et al., 2016). Pre- and post-monitoring are useful for managers to understand the actual results of specific decisions made (Lempert et al., 2013). But, in reality, long-time monitoring is challenging for fisheries management because it is usually difficult to maintain funding support for extended periods. Moreover, political change and disturbance can place funding in jeopardy.

3.8.8 Other responses

There are also other responses in the reviewed articles, which make great contributions to inland fisheries management. These provide inland fisheries managers and decision makers with valuable examples of how to better deal with the fisheries sector. For example, fish stock-specific management (Martins et al., 2011), distinct fisheries management (Martins et al., 2011), integration of local knowledge and political intervention options (Morrogongiello et al., 2011; Béné & Friend, 2009) are all useful in promoting the sustainability of inland fisheries.

While the latter practices are beyond the scope of this thesis, it should be noted that these approaches can be employed alone or combined to address challenges in inland fisheries management. For example, adaptive management is very flexible and can be applied in different contexts and situations along with ecosystem-based approaches (Poesch et al., 2016; Lynch et al., 2016) or resilience management tactics (Paukert et al., 2016). Human induced climate change implies substantial risks for inland fish and other biota. Reducing these risks involves responses to climate change, such as mitigation and adaptation.

In the climate change context, mitigation means limiting global climate change by reducing greenhouse gas emissions or enhancing the efficiency of major carbon sinks such as forests or oceans. In contrast, adaptation means actions targeted at the vulnerable system with the objective of moderating harm from climate change (McCarthy et al., 2001). Mitigation and adaptation measures for responses to current fisheries problems are necessary and need to be done effectively to prevent further loss of aquatic ecosystem and fisheries resources.

3.9 Uncertainty

Unpredictable risks and considerable uncertainty are also involved in climate change impacts (IPCC, 2014). Therefore, it is hard to evaluate climate change impacts on ecosystem services over a longer time period and with high risk and uncertainty (IPCC, 2014). It is generally accepted that prediction of climate change impacts on freshwater ecosystems is full of uncertainties and requires more research. However, current research appears to deal lightly with uncertainties and the role it plays on management of inland fisheries. Indeed, how experts should best characterize such uncertainties for decision-makers remains as an important debate (Lempert, Nakicenovic, Sarewitz & Schlesinger, 2004). More than half of the articles reviewed do not refer to uncertainties or the ways to deal with possible uncertainties. Quantifying value and risk is mentioned only once from selected articles (Hughes et al., 2000), which shows that there is not enough attention given to this problem faced by fisheries managers.

The management of fisheries is becoming more complex because it is underpinned with various drivers and requires an integrated framework to investigate the complicated dynamics of factors that impact on it. Despite the long-time knowledge of fisheries management, and appropriate policy responses, uncertainty regarding climate change makes its incorporation into policy a daunting task (Paukert et al., 2016; Hansen et al., 2015). One notable manifestation of uncertainties in fisheries management is predicting impacts from both climatic and non-climatic factors

(Cochrane et al., 2009). Inland aquatic ecosystems may be affected mostly due to climate change (Barange & Perry 2009; Bates et al., 2008), which is also one of the uncertain factors that are influencing fish populations and their response to management (Hansen et al., 2015). Variability of environmental conditions such as temperature, river runoff and precipitation might be caused by climate change (Kundezewicz et al., 2008), and will impact ecosystems, societies, economics, food securities, livelihoods as well as fisheries (Allison et al., 2009; FAO, 2010). The extent to which climate change impacts particular fisheries relies largely on the adaptive capacity of an ecosystem (Suuronen & Bartley, 2014). Both negative and positive effects of climate change on inland fisheries vary widely from location to location, causing further uncertainties to its effects.

Despite increased attempts to address hydrological processes and pathways, there is a paucity of information on which to base current models and decision-making. More investigation about hydrological regimes and weather pattern changes due to climate change is needed, such as further study and attempts to gain consensus globally (Ficke et al., 2007), which increases the uncertain factors of climate change and reduces other possibilities of opportunities and challenges. It is important to ensure robust strategies and scientific knowledge to support the health of freshwaters which underpin inland fisheries management. Additionally, fish managers should take uncertainty into consideration when employing various management approaches (Hague & Patterson, 2014; Paukert et al., 2017). That is, uncertainties should be incorporated into the management scope to ensure managers prepare the unexpected situations ahead, most notably, future climate change scenarios.

3.10 Policy gap analysis

Climate change impacts bring threats and challenges as well as potential opportunities for social and economic aspects of fisheries; its impacts and vulnerabilities have been figured out so far mainly on the basis of scientific knowledge such as models and specific location-based case studies (Arnell, 2004; Smit & Pilifosova, 2001). Inland fisheries policy makers and managers have succeeded in highlighting many challenges and stressors in management regulations such as exploitation restrictions, stock enhancement, and invasive species control and so on (Arlinghaus et al., 2016). New challenges and opportunities are emerging even though some of the problems are alleviated by human interventions.

Clearly, there is a huge gap between the current response systems and the climate change challenges in inland fisheries. About 24% of the articles do not propose any responses or recommendations to the status of inland fisheries sector. Charismatic species and habitats' conservation have been emphasized and therefore given more attention by the governments, mostly because fish resources have significant monetary value and fisheries policy makers always want to achieve the maximum benefits. Many articles also point out the need for responses and recommend some approaches for better management of inland fisheries as have been summarized above. Assessment and management have been described as inadequate or absent (Andrew et al., 2007) and this has the potential to worsen in the near future to further inhibit social change. The limited scientific research information for policy planners continue to limit the understanding of potential impacts of climate change. More management options need to be explored and climate change impacts need to be incorporated into policy discussions and guidelines to help protect inland fisheries resources.

3.11 Challenges for inland fisheries management

Drivers and pressures vary and are associated with different contexts thus posing additional challenges to the management process. People, ecosystems and diversity are intertwined and the provision of ecosystem services including fisheries may be interacting with many environmental change drivers and could be faced with more challenges in the future.

One key challenge to managers and decision-makers tasked with sustaining inland fisheries is the multifarious nature of environmental change. Indeed, it is often the case that no single source of stress can explain environmental variation observed in the field. For this reason, increased attention has been given to multiple stressors (Ormerod et al., 2010). Multiple stressors that threaten freshwater ecosystems result in additive, antagonistic, or synergistic responses. Ormerod et al. (2010) argue that freshwaters appear to be at particular risk of multiple-stressor effects, perhaps because multiple uses of water and the protection of freshwater environments often conflict. As well, Hecky et al. (2010) notes that multiple-stressor effects may develop through nonlinear or delayed interactions in systems, thereby casting doubt on many studies that offer simple linear or direct relationships. Human activities such as economic development and legal institutions continue to deeply influence nature (De Chazal & Rounsevell, 2009; Luck et al., 2009; Hassan, 2005), which can lead to environmental changes to a large extent and cause changes in ecosystem services. The human responses to climate change may create new unpredictable challenges together with climate change itself, which need new adaptive systems (Hunt et al., 2016). For example, the use of a new technology like trawling, which was meant to make fishing effective, ended up making fisheries unsustainable.

There are other challenges fisheries policy makers need to consider: the lack of long-term monitoring or funding source is a major problem in some countries. And also, information or data sometimes are not sufficient or is manipulated. For example, in some cases, data are limited and not available such as in South American and Asian countries. Failure to communicate effectively among different stakeholders can also be challenging in achieving sustainable goals for inland fisheries management. The dialogue among scientists, local people's knowledge and policy makers should be enhanced to achieve the sustainable goals for management (Hallwass et al., 2013). Government and other institutions or groups from different cultures use distinct languages for communication pertaining to certain issues. Moreover, their value systems are also very different. For example, people's perceptions about things can be influenced by local cultures or traditions and political ideas or biases (Maurstad et al., 2007). Béné et al. (Béné et al., 2016)'s evaluation reveals that evidence-based research and policy narratives are often disconnected, with some of the strongest and long-lasting policy narratives lacking any strong and rigorous evidence-based validation. Fisheries management sometimes is not in line with the scientific information, yet, policy makers have to make decisions without enough information or before they get scientific results (Axelrod, 2011). It is also important to note that decision making involves not only scientific knowledge but also knowledge of the social and economic context (interest or benefits incentives or immediate interests in most of cases) as well as political dynamics (Lynch, Varela-Acevedo & Taylor, 2015). The science-policy gap/tension needs more attention when making policy actions and identifying challenges. Another challenge to address is the stakeholders' attitudes towards uncertainty. Admitting uncertainty may cause discomfort among stakeholders in fisheries management because it could undermine projections and forecast, especially when dealing with actors with divergent views and interests (Walters, 2007). They all show that stronger interface between government, the public and other stakeholders will be very beneficial for fisheries managers to make efficient and effective decisions.

Chapter 4

4.1 Conclusion

This thesis has discussed the impact of climate change on inland fisheries, and how the phenomenon of climate change might be incorporated into management decisions. It has become clear that climate change impacts on freshwater ecosystems will complicate future freshwater management regimes with consequences for the fisheries sector. It is also evident that climate change does not act in isolation. Multiple drivers, including climate change and other stressors with complex interactions influence the status of freshwater fisheries and their concomitant natural ecosystems. That is, inland fisheries management is challenged by multiple threats and pressures, notably climate change, non-native species introduction, water pollution, dam construction, and habitat degradation. The measures taken by governments are not as effective as expected; there are still many issues facing the sector and some are expected to worsen. Exploitation regulation, stock enhancement activities and designation of nature reserves are all examples of measures taken as current precautionary actions. Unfortunately, these measures have often led to disappointment and the results cannot meet the goal of sustainable fishing.

Reducing climate change impacts on inland fisheries is a major task in inland fisheries management. Mitigation and adaptive measures should be improved and implemented effectively. Effective inland fisheries and aquaculture management can alleviate climate change’s impacts and provide good solutions for food security enhancement for poor and marginalized people and social-economic development in general (Das & Sharma, 2010). Methods to improve aquatic ecosystem resilience, to reduce GHG emissions in inland fisheries sectors, and to make good use of opportunities to deal with potential threats of food security and livelihood should be incorporated into inland fisheries management decisions under climate change scenarios.

4.2 Research limitations

Only articles in English language were included in the systematic review. There are many other articles from non-English speaking countries, but these were excluded and may have biased the results. There were around 20 articles which offered valuable information about inland fisheries and aquaculture management, but they were excluded because they targeted review articles. Their inclusion could have led to duplication since most of them might have derived their findings from the same articles used in this thesis. Also, the scope of the review was limited, one that was suitable to a timeframe and an effort suitable for a master's level enquiry. However, the support of friends who made inputs and gave feedback to the review process helped minimize the effects of the "one-person effect".

4.3 Future directions

Climate change and its associated effects are among the most important threats to the fisheries sector. These threats could worsen in the future. This thesis reveals that substantial strides are being made in developing resilient systems. Continued adaptation and decision making based on long-term monitoring will help advance knowledge on the effects of climate change on fish and fisheries, aquatic communities, and the users of these resources. Assessment about how climate change affects inland fisheries and aquaculture should be regarded as a focus to guide decision making; assessment studies are very important because of the limitation of current available data and research effort. Specific species' reactions to climatic impacts also need to be further researched and linked to the policy-making process to reduce risks. The livelihood approach to assess impacts of climate change to reduce poverty in particular in SSF can also provide a way to improve the vulnerable livelihoods for fishers or local communities (Daw, Adger, Brown & Badjeck, 2009) plus the existing fisheries assessment methods. It is recommended that managers should consider using evidence-based decision making and develop more accurate predictive models and long-term monitoring programs beyond traditional boundaries in inland fisheries management.

References

Alho, C. J., Reis, R. E., & Aquino, P. P. (2015). Amazonian freshwater habitats experiencing environmental and socioeconomic threats affecting subsistence fisheries. *Ambio*, *44*(5), 412-425. DOI 10.1007/s13280-014-0610-z

Allan JD, Palmer M, Poff NL (2005) Climate change and freshwater ecosystems. In: Lovejoy TE, Hannah L (eds) *Climate change and biodiversity*, 274–295. Yale University Press, New Haven, CT-USA.

Allen, T., Southwick, R., & Howlett, D. (2013). Sportfishing in America: an economic force for conservation. *American Sportfishing Association, Alexandria, Virginia, USA*.

Allison, E. H., Andrew, N. L., & Oliver, J. (2007). Enhancing the resilience of inland fisheries and aquaculture systems to climate change. *Journal of SAT Agricultural Research,* 4(1), 1-25. Retrieved 05/07/2018 from https://www.researchgate.net/profile/Edward_Allison/publication/26529879_Enhancing_the_resilience_of_inland_fisheries_and_aquaculture_systems_to_climate_change/links/0fcfd50d3291f3be30000000.pdf

Andrew, N. L., Béné, C., Hall, S. J., Allison, E. H., Heck, S., & Ratner, B. D. (2007). Diagnosis and management of small-scale fisheries in developing countries. *Fish and Fisheries*, *8*(3), 227-240. DOI- https://doi.org/10.1111/j.1467-2679.2007.00252.x

Arctic Climate Impact Assessment. (ACIA) (2004). Impacts of a Warming Arctic-Arctic Climate Impact Assessment. In *Impacts of a Warming Arctic-Arctic Climate Impact Assessment, by Arctic Climate Impact Assessment,* pp. 144. Cambridge University Press*:* Cambridge-UK:

Arlinghaus R., Mehner T. & Cowx I.G. (2002). Reconciling traditional inland fisheries management and sustainability in industrialized countries, with emphasis on Europe. *Fish and Fisheries,* 3, 261–316. DOI- https://doi.org/10.1046/j.1467-2979.2002.00102.x

Arlinghaus, R., S. J. Cooke, and W. Potts. (2013). Towards resilient recreational fisheries on a global scale through improved understanding of fish and fisher behavior. *Fisheries Management and Ecology*, 20(2–3), 91–98. DOI- https://doi.org/10.1111/fme.12027

Atkins, J. P., Burdon, D., Elliott, M., & Gregory, A. J. (2011). Management of the marine environment: integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach. *Marine pollution bulletin*, *62*(2), 215-226.

Axelrod, M. (2011). Climate change and global fisheries management: linking issues to protect ecosystems or to save political interests? *Global Environmental Politics*, *11*(3), 64-84. DOI- https://doi.org/10.1162/GLEP_a_00069

Badjeck, M. C., Allison, E. H., Halls, A. S., & Dulvy, N. K. (2010). Impacts of climate variability and change on fishery-based livelihoods. *Marine policy*, *34*(3), 375-383. DOI- https://doi.org/10.1016/j.marpol.2009.08.007

Bartley, D. M., De Graaf, G. J., Valbo-Jørgensen, J., & Marmulla, G. (2015). Inland capture fisheries: status and data issues. *Fisheries Management and Ecology*, *22*(1), 71-77.

Bates B.C., Kundzewicz Z.W., Wu S. & Palutikof J.P. (eds.) (2008). *Climate change and water*. Technical paper of the IPCC, IPCC Secretariat, Geneva-Switzerland.

Beddington, J. R., Agnew, D. J., & Clark, C. W. (2007). Current problems in the management of marine fisheries. *science*, *316*(5832), 1713-1716.

Bell. S., & Morse, S. (2003). Measuring Sustainability. Learning from Doing. Earthscan Publications Ltd: London-UK.

Béné, C., & Friend, R. M. (2009). Water, poverty and inland fisheries: lessons from Africa and Asia. *Water International*, *34*(1), 47-61. DOI- https://doi.org/10.1080/02508060802677838

Béné, C., Arthur, R., Norbury, H., Allison, E. H., Beveridge, M., Bush, S., ... & Thilsted, S. H. (2016). Contribution of fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. *World Development*, *79*, 177-196. DOI- https://doi.org/10.1016/j.worlddev.2015.11.007

Bertahas, I., Dimitriou, E., Karaouzas, I., Laschou, S., & Zacharias, I. (2006). Climate change and agricultural pollution effects on the trophic status of a Mediterranean lake. *CLEAN–Soil, Air, Water*, *34*(4), 349-359. DOI- https://doi.org/10.1002/aheh.200500637

Blair, J. M., Ostrovsky, I., Hicks, B. J., Pitkethley, R. J., & Scholes, P. (2013). Growth of rainbow trout (Oncorhynchus mykiss) in warm-temperate lakes: implications for environmental change. *Canadian Journal of Fisheries and Aquatic Sciences*, *70*(5), 815-823. DOI- https://doi.org/10.1139/cjfas-2012-0409

Boon, E., & Ahenkan, A. (2012). Assessing climate change impacts on ecosystem services and livelihoods in Ghana: Case study of communities around Sui Forest Reserve. Retrieved 03/07/2018 from http://ugspace.ug.edu.gh/handle/123456789/6554

Borja, A., Bricker, S. B., Dauer, D. M., Demetriades, N. T., Ferreira, J. G., Forbes, A. T., ... & Zhu, C. (2008). Overview of integrative tools and methods in assessing ecological integrity in estuarine and coastal systems worldwide. *Marine pollution bulletin*, *56*(9), 1519-1537.

Borja, A., Galparsoro, I., Solaun, O., Muxika, I., Tello, E. M., Uriarte, A., & Valencia, V. (2006). The European Water Framework Directive and the DPSIR, a methodological approach to assess the risk of failing to achieve good ecological status. *Estuarine, coastal and shelf science*, *66*(1-2), 84-96.

Bostock, J., McAndrew, B., Richards, R., Jauncey, K., Telfer, T., Lorenzen, K., ... & Corner, R. (2010). Aquaculture: global status and trends. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *365*(1554), 2897-2912.

Bowen, R. E., & Riley, C. (2003). Socio-economic indicators and integrated coastal management. *Ocean & Coastal Management*, *46*(3-4), 299-312. DOI- https://doi.org/10.1016/S0964-5691(03)00008-5

Brander, K. M. (2007). Global fish production and climate change. *Proceedings of the National Academy of Sciences*, *104*(50), 19709-19714. DOI- https://doi.org/10.1073/pnas.0702059104

Brown, J. J., Limburg, K. E., Waldman, J. R., Stephenson, K., Glenn, E. P., Juanes, F., & Jordaan, A. (2013). Fish and hydropower on the US Atlantic coast: failed fisheries policies from half-way technologies. *Conservation Letters*, *6*(4), 280-286. DOI- https://doi.org/10.1111/conl.12000

Brummett, R. E., Beveridge, M. C., Chimatiro, S., Katiha, P., King, J., Kolding, J., ... & Turpie, J. 12 Inland fisheries and aquaculture. Freshwater Fisheries. Retrived 12/04/2018 from https://www.researchgate.net/profile/Jeppe_Kolding/publication/237136604_Inland_fisheries_and_aquaculture/links/54e70a920cf277664ff7778a/Inland-fisheries-and-aquaculture.pdf

Bryant, M. D. (2009). Global climate change and potential effects on Pacific salmonids in freshwater ecosystems of southeast Alaska. *Climatic Change*, *95*(1-2), 169-193. DOI 10.1007/s10584-008-9530-x

Burkhard, B. & Müller, F. (2012). The indicator side of ecosystem services. *Ecosystem Services*, *1*(1), 26-30. DOI- https://doi.org/10.1016/j.ecoser.2012.06.001

Carpenter, S. R., K. J. Arrow, S. Barrett, R. Biggs, W. A. Brock, A.-S. Crépin, G. Engström, C. Folke, T. P. Hughes, N. Kautsky, C.-Z. Li, G. McCarney, K. Meng, K.-G. Mäler, S. Polasky, and coauthors. 2012. General resilience to cope with extreme events. *Sustainability* 4:3248–3259. DOI- 10.3390/su4123248

Carr, E. R., Wingard, P. M., Yorty, S. C., Thompson, M. C., Jensen, N. K., & Roberson, J. (2007). Applying DPSIR to sustainable development. *International Journal of Sustainable Development & World Ecology*, *14*(6), 543-555. DOI- https://doi.org/10.1080/13504500709469753

Chu, C., Minns, C. K., Lester, N. P., & Mandrak, N. E. (2014). An updated assessment of human activities, the environment, and freshwater fish biodiversity in Canada. *Canadian journal of fisheries and aquatic sciences*, *72*(1), 135-148. DOI- https://doi.org/10.1139/cjfas-2013-0609

Civantos, E., Thuiller, W., Maiorano, L., Guisan, A., & Araújo, M. B. (2012). Potential impacts of climate change on ecosystem services in Europe: the case of pest control by vertebrates. *BioScience*, *62*(7), 658-666

Cochrane, K., De Young, C., Soto, D., & Bahri, T. (2009). Climate change implications for fisheries and aquaculture. *FAO Fisheries and aquaculture technical paper*, *530*, 212. Retrieved 02/06/2018 from https://pdfs.semanticscholar.org/c598/b10f1b4e3d3804977ef65d3426d8ba7a2683.pdf

Cochrane, K. L. (Ed.). (2002). *A fishery manager's guidebook: management measures and their application* (No. 424). Food & Agriculture Organization.

Cohen, A. S., Gergurich, E. L., Kraemer, B. M., McGlue, M. M., McIntyre, P. B., Russell, J. M., ... & Swarzenski, P. W. (2016). Climate warming reduces fish production and benthic habitat in Lake Tanganyika, one of the most biodiverse freshwater ecosystems. *Proceedings of the National Academy of Sciences*, *113*(34), 9563-9568. DOI- https://doi.org/10.1073/pnas.1603237113

Collares-Pereira, M. J., & Cowx, I. G. (2004). The role of catchment scale environmental management in freshwater fish conservation. *Fisheries management and Ecology*, *11*(3-4), 303-312. DOI- https://doi.org/10.1111/j.1365-2400.2004.00392.x

Collares-Pereira, M. J., & Cowx, I. G. (2004). The role of catchment scale environmental management in freshwater fish conservation. *Fisheries Management and Ecology*, *11*(3-4), 303-312. DOI- https://doi.org/10.1111/j.1365-2400.2004.00392.x

Collen, B., Whitton, F., Dyer, E. E., Baillie, J. E., Cumberlidge, N., Darwall, W. R., ... & Böhm, M. (2014). Global patterns of freshwater species diversity, threat and endemism. *Global Ecology and Biogeography*, *23*(1), 40-51. DOI- https://doi.org/10.1111/geb.12096

Condie, S. A., Hayes, D., Fulton, E. A., & Savina, M. (2012). Modelling ecological change over half a century in a subtropical estuary: impacts of climate change, land-use, urbanization and freshwater extraction. *Marine Ecology Progress Series*, *457*, 43-66. DOI- https://doi.org/10.3354/meps09718

Cooke, S. J., Arlinghaus, R., Johnson, B. M., & Cowx, I. G. (2016). Recreational fisheries in inland waters. In *Freshwater fisheries ecology*, 449-465. Wiley, Sussex, UK,

Crivelli, A. J. (2002). The role of protected areas in freshwater fish conservation. In *Conservation of freshwater fishes: options for the future*, 373-388. Blackworld Science: London-UK.

Crook, D. A., Reich, P., Bond, N. R., McMaster, D., Koehn, J. D., & Lake, P. S. (2010). Using biological information to support proactive strategies for managing freshwater fish during drought. *Marine and Freshwater Research*, *61*(3), 379-387. DOI- https://doi.org/10.1071/MF09209

Das, M. K., & Sharma, A. P. (2010). Add Fisheries and Aquaculture management to our solutions for Climate Change and Food Security (CIFRI Bulletin no. 167). Retrieved 05/07/2018 from http://krishikosh.egranth.ac.in/bitstream/1/59796/1/Bulletin%20No.167.pdf

Das, M. K., Sharma, A. P., Sahu, S. K., Srivastava, P. K., & Rej, A. (2013). Impacts and vulnerability of inland fisheries to climate change in the Ganga River system in India. *Aquatic ecosystem health & management*, *16*(4), 415-424. DOI- https://doi.org/10.1080/14634988.2013.851585

David G. Angeler, Craig R. Allen, Hannah E. Birgé, Stina Drakare, Brendan G. McKie, Richard K. Johnson Ambio. (2014) Dec; Assessing and managing freshwater ecosystems vulnerable to environmental change; 43(Suppl 1): 113–125. Published online 2014 Nov 15. DOI- 10.1007/s13280-014-0566-z PMCID: PMC4235931

Daw, T.; Adger, W.N.; Brown, K.; Badjeck, M.-C. 2009. Climate change and capture fisheries: potential impacts, adaptation and mitigation. In K. Cochrane, C. De Young, D. Soto and T. Bahri (eds). Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. *FAO Fisheries and Aquaculture Technical Paper.* No. 530. Rome, FAO. pp.107-150. Retrieved 05/07/2018 from http://www.fao.org/fileadmin/user_upload/newsroom/docs/FTP530.pdf#page=113

Day, J. C., & Roff, J. C. (2000). *Planning for representative marine protected areas: a framework for Canada's oceans*. World Wildlife Fund Canada: Toronto-Canada.

De Silva, S. S., & Hasan, M. R. (2007). Feeds and fertilizers: the key to long-term sustainability of Asian aquaculture. *FAO Fisheries Technical Paper*, *497*, 19. Rome, FAO. Retrieved 12/05/2018 from https://www.researchgate.net/profile/Manjurul_Karim2/publication/289541103_

Drammeh, O. K. L.(2000). Illegal, Unreported & Unregulated Fishing In Small-Scale Marine And Inland Capture Fisheries. Document AUS:IUU/2000/7. 2000. 7 p.

Dudgeon, D. (2000). Large-Scale Hydrological Changes in Tropical Asia: Prospects for Riverine Biodiversity: The construction of large dams will have an impact on the biodiversity of tropical Asian rivers and their associated wetlands. *BioScience*, *50*(9), 793-806. DOI: 10.1641/0006-3568(2000)050[0793:lshcit]2.0.co;2

Dulvy, N. K., Reynolds, J. D., Pilling, G. M., Pinnegar, J. K., Phillips, J. S., Allison, E. H., & Badjeck, M. C. (2011). Fisheries management and governance challenges in a climate change. In *The economics of adapting fisheries to climate change*, 31-89. OECD Publishing, Paris, France, https://doi.org/10.1787/9789264090415-en.

Eby, L. A., Helmy, O., Holsinger, L. M., & Young, M. K. (2014). Evidence of climate-induced range contractions in bull trout Salvelinus confluentus in a Rocky Mountain watershed, USA. *PLoS One*, *9*(6), e98812.

Edge, C. B., Fortin, M. J., Jackson, D. A., Lawrie, D., Stanfield, L., & Shrestha, N. (2017). Habitat alteration and habitat fragmentation differentially affect beta diversity of stream fish communities. *Landscape ecology*, *32*(3), 647-662.

Elliott, J., & Elliott, J. A. (2010). Temperature requirements of Atlantic salmon Salmo salar, brown trout Salmo trutta and Arctic charr Salvelinus alpinus: predicting the effects of climate change. *Journal of fish biology*, *77*(8), 1793-1817. DOI-https://doi.org/10.1111/j.1095-8649.2010.02762.x

European Environmental Agency (EEA). (1997) "Environmental Terminology and Discovery Service". Retrieved 01/07/2018 from http://glossary.eea.europa.eu/terminology/concept_html?term=dpsir.13/02/2018

FAO (2003). (FAO) Rome, Review of the state of the world fisheries resources: inland waters. Retrieved 02/07/2018 from http://www.fao.org/tempref/docrep/fao/006/J0703e/j0703e00.pdf

FAO (2010). *The state of world fisheries and aquaculture 2010*. FAO, Rome- Italy. Retrieved 02/07/2018 from http://www.fao.org/3/a-i1820e.pdf

FAO (2014) State of World Fisheries and Aquaculture, 2014 223. Food and Agriculture Organization of the United Nations, Rome- Italy. Retrieved 02/07/2018 from http://www.fao.org/3/a-i3720e.pdf

FAO (2016). Aquaculture Department (2010). The state of world fisheries and aquaculture. *Food and Agriculture Organization of the United Nations*, *Rome-* Italy. Retrieved 02/07/2018 from http://www.fao.org/3/a-i5555e.pdf

Food and Agriculture Organization of the United Nations (FAO) and World Fish Center (2008). Small-Scale Capture Fisheries – *A Global Overview with Emphasis on Developing Countries. A preliminary report of the Big Numbers Project*. Retrieved 13/08/2018 from http://pubs.iclarm.net/resource_centre/Big_Numbers_Project_Preliminary_Report.pdf

Fausch, K. D., Torgersen, C. E., Baxter, C. V., & Li, H. W. (2002). Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes: A continuous view of the river is needed to understand how processes interacting among scales set the context for stream fishes and their habitat. *AIBS Bulletin*, *52*(6), 483-498. DOI- https://doi.org/10.1641/0006-3568

Feld C.K., Sousa J.P., da Silva P.M., Dawson T.P. (2010). A framework to assess indicators of biodiversity and ecosystem services: implications for indicator development. *Biodiversity and Conservation*, *19*(10), 2895-2919. DOI- 10.1111/j.1600-0706.2009.17860.x,

Ferguson, J. W., Healey, M., Dugan, P., & Barlow, C. (2011). Potential effects of dams on migratory fish in the Mekong River: Lessons from salmon in the Fraser and Columbia Rivers. *Environmental Management*, *47*(1), 141-159. DOI 10.1007/s00267-010-9563-6

Ficke, A. D., Myrick, C. A., & Hansen, L. J. (2007). Potential impacts of global climate change on freshwater fisheries. *Reviews in Fish Biology and Fisheries*, *17*(4), 581-613. DOI- DOI 10.1007/s11160-007-9059-5

Ficke, A. D., Myrick, C. A., & Hansen, L. J. (2007). Potential impacts of global climate change on freshwater fisheries. *Reviews in Fish Biology and Fisheries*, *17*(4), 581-613. DOI 10.1007/s11160-007-9059-5

Franklin, P. A. (2014). Dissolved oxygen criteria for freshwater fish in New Zealand: a revised approach. *New Zealand Journal of Marine and Freshwater Research*, *48*(1), 112-126. DOI- https://doi.org/10.1080/00288330.2013.827123

Fussell, K. M. D., Smith, R. E., Fraker, M. E., Boegman, L., Frank, K. T., Miller, T. J., ... & Hecky, R. E. (2016). A perspective on needed research, modeling, and management approaches that can enhance Great Lakes fisheries management under changing ecosystem conditions. *Journal of Great Lakes Research*, *42*(4), 743-752. DOI- https://doi.org/10.1016/j.jglr.2016.04.007

Gabrielson, P., & Bosch, P. (2003). Environmental indicators: typology and use in reporting. *EEA, Copenhagen*-Denmark. Retrieved 12/07/2018 from http://www.brahmatwinn.uni-jena.de/fileadmin/Geoinformatik/projekte/brahmatwinn/Workshops/FEEM/Indicators/EEA_Working_paper_DPSIR.pdf

Gallopin, G. C. (1997). Indicators and their use: information for decision-making. *Scope-Scientific Committee on Problems of the Environment International Council of Scientific Unions*, *58*, 13-27.

Galloway, B. T., Muhlfeld, C. C., Guy, C. S., Downs, C. C., & Fredenberg, W. A. (2016). A framework for assessing the feasibility of native fish conservation translocations: applications to threatened Bull Trout. *North American Journal of Fisheries Management*, *36*(4), 754-768. DOI- https://doi.org/10.1080/02755947.2016.1146177

Grantham, R. W., & Rudd, M. A. (2015). Current status and future needs of economics research of inland fisheries. *Fisheries Management and Ecology*, *22*(6), 458-471. DOI- https://doi.org/10.1111/fme.12144

Graves, D., & Maule, A. (2014). A stakeholder project to model water temperature under future climate scenarios in the Satus and Toppenish watersheds of the Yakima River Basin in Washington, USA. *Climatic change*, *124*(1-2), 399-411. DOI 10.1007/s10584-012-0643-x

Green, B. N., Johnson, C. D., & Adams, A. (2006). Writing narrative literature reviews for peer-reviewed journals: secrets of the trade. *Journal of Chiropractic Medicine*, *5*(3), 101-117. DOI-10.1016/S0899-3467(07)60142-6

Groll, M., Kulmatov, R., Mullabaev, N., Opp, C., & Kulmatova, D. (2016). Rise and decline of the fishery industry in the Aydarkul–Arnasay Lake System (Uzbekistan): effects of reservoir management, irrigation farming and climate change on an unstable ecosystem. *Environmental Earth Sciences*, *75*(10), 921. DOI 10.1007/s12665-016-5691-5

Hague, M. J., & Patterson, D. A. (2014). Evaluation of statistical river temperature forecast models for fisheries management. *North American Journal of Fisheries Management*, *34*(1), 132-146. DOI- https://doi.org/10.1080/02755947.2013.847879

Hansen, G. J., Gaeta, J. W., Hansen, J. F., & Carpenter, S. R. (2015). Learning to manage and managing to learn: sustaining freshwater recreational fisheries in a changing environment. *Fisheries*, *40*(2), 56-64. DOI-https://doi.org/10.1080/03632415.2014.996804

Hardi, P., & Canada. Industry Canada. (1997). *Measuring sustainable development: Review of current practice*. Industry Canada. Retrieved 12/07/2018 from https://www.ic.gc.ca/eic/site/eas-aes.nsf/vwapj/op17e.pdf/$file/op17e.pdf

Harrold, M., Agrawala, S., Steele, P., Sharma, A., Hirsch, D., Liptow, H., ... & Kashyap, A. (2002). Poverty and climate change: Reducing the vulnerability of the poor through adaptation. Retrieved 10/07/2018 from http://agris.fao.org/agris-search/search.do?recordID=US2012416506

Healey, M. (2011). The cumulative impacts of climate change on Fraser River sockeye salmon (Oncorhynchus nerka) and implications for management. *Canadian Journal of Fisheries and Aquatic Sciences*, *68*(4), 718-737. DOI-https://doi.org/10.1139/f2011-010

Heino, J., Virkkala, R., & Toivonen, H. (2009). Climate change and freshwater biodiversity: detected patterns, future trends and adaptations in northern regions. *Biological Reviews*, *84*(1), 39-54. DOI- https://doi.org/10.1111/j.1469-185X.2008.00060.x

Heino, J., Virkkala, R., & Toivonen, H. (2009). Climate change and freshwater biodiversity: detected patterns, future trends and adaptations in northern regions. *Biological Reviews*, *84*(1), 39-54. DOI-https://doi.org/10.1111/j.1469-185X.2008.00060.x

Helfman, G., Collette, B. B., Facey, D. E., & Bowen, B. W. (2009). *The diversity of fishes: biology, evolution, and ecology*. John Wiley & Sons: Hoboken, New Jersey, United States.

Hershkovitz, Y., Strackbein, J. & Hering, D. (2013). Climate-and-freshwater. InfoVersion: January 2014. Accessed on 07/11/2017 www.climate-and-freshwater.info

Hobday, A. J., & Lough, J. M. (2011). Projected climate change in Australian marine and freshwater environments. *Marine and Freshwater Research*, *62*(9), 1000-1014. DOI- https://doi.org/10.1071/MF10302

Hollowed, A. B., Barange, M., Beamish, R. J., Brander, K., Cochrane, K., Drinkwater, K., ... & Kim, S. (2013). Projected impacts of climate change on marine fish and fisheries. *ICES Journal of Marine Science*, *70*(5), 1023-1037. DOI- https://doi.org/10.1093/icesjms/fst081

Hou, Y., Zhou, S., Burkhard, B., & Müller, F. (2014). Socioeconomic influences on biodiversity, ecosystem services and human well-being: A quantitative application of the DPSIR model in Jiangsu, China. *Science of the Total Environment*, 490, 1012-1028. DOI- https://doi.org/10.1016/j.scitotenv.2014.05.071

Hughes, S., & Morley, S. (2000). Aspects of fisheries and water resources management in England and Wales. *Fisheries Management and Ecology*, *7*(1-2), 75-84. DOI- https://doi.org/10.1046/j.1365-2400.2000.00180.x

Hyatt, K. D., Stockwell, M. M., & Rankin, D. P. (2003). Impact and adaptation responses of Okanagan River sockeye salmon (Oncorhynchus nerka) to climate variation and change effects during freshwater migration: stock restoration and fisheries management implications. *Canadian Water Resources Journal*, *28*(4), 689-713. DOI- https://doi.org/10.4296/cwrj2804689

IFAD (2011) IFAD Strategic Framework 2011–2015. IFAD, Rome, Italy, 33 pp. Available at: https://www.ifad.org/documents/10180/3e9c6239-449e-4dba-951a-849e301616d5 Retrieved from 04/04/2018.

Intergovernmental Panel on Climate Change (IPCC), Core Writing Team (2007) Climate Change 2007: Synthesis Report. No. 104. Retrieved 11/07/2018 from https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_full_report.pdf

Intergovernmental Panel on Climate Change (IPCC), (2001b). 'Climate Change 2001: Impacts, Adaptation & Vulnerability', Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate

Change, McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken D. J., and White, K. S., (eds.), Cambridge University Press, U.K

Intergovernmental Panel on Climate Change (IPCC), (2014). Summary for Policymakers. Climate Change 2014: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Retrieved 07/07/2018 from https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-IntegrationBrochure_FINAL.pdf

Jackson, M. C., Loewen, C. J., Vinebrooke, R. D., & Chimimba, C. T. (2016). Net effects of multiple stressors in freshwater ecosystems: a meta-analysis. *Global Change Biology*, *22*(1), 180-189. DOI- https://doi.org/10.1111/gcb.13028

Jackson, M. C., Woodford, D. J., & Weyl, O. L. (2016). Linking key environmental stressors with the delivery of provisioning ecosystem services in the freshwaters of southern Africa. *Geo: Geography and Environment*, *3*(2), e00026. DOI- https://doi.org/10.1002/geo2.26

Jayasinghe, H. D. & Niroshana, K. H. H. (2016). Potential impacts of climate change on fishereis and aquaculture in Sri Lanka, *Journal of Fisheries science and Technology, 4(1), 11-16.* Retrieved 05/07/2018 from https://www.researchgate.net/profile/Anuradhi_Jayasinghe3/publication/306347550

Johnson, J. E., & Welch, D. J. (2009). Marine fisheries management in a changing climate: a review of vulnerability and future options. *Reviews in Fisheries Science*, *18*(1), 106-124.

Jones, P. D., Lister, D. H., Wilby, R. L., & Kostopoulou, E. (2006). Extended river flow reconstructions for England and Wales, 1865–2002. *International Journal of Climatology*, *26*(2), 219-231. DOI- https://doi.org/10.1002/joc.1252

Karageorgis, A. P., Kapsimalis, V., Kontogianni, A., Skourtos, M., Turner, K. R., & Salomons, W. (2006). Impact of 100-year human interventions on the deltaic coastal zone of the inner Thermaikos Gulf (Greece): A DPSIR framework analysis. *Environmental Management*, *38*(2), 304-315. DOI- 10.1007/s00267-004-0290-8

Kawarazuka, N., & Béné, C. (2011). The potential role of small fish species in improving micronutrient deficiencies in developing countries: building evidence. *Public Health Nutrition*, *14*(11), 1927-1938. DOI- é (a1) https://doi.org/10.1017/S1368980011000814

Kelble, C. R., Loomis, D. K., Lovelace, S., Nuttle, W. K., Ortner, P. B., Fletcher, P., Boyer, J. N. (2013). The EBM-DPSER conceptual model: integrating ecosystem services into the DPSIR framework. *PlOS ONE,* 8(8). Retrieved 10/07/2018 from https://doi.org/10.1371/journal.pone.0070766 15/03/2018

Kernan, M., Battarbee, R. W., & Moss, B. R. (Eds.). (2011). *Climate change impacts on freshwater ecosystems*. John Wiley & Sons. Chichester, UK.

Kidwai, S., Fanning, P., Ahmed, W., Tabrez, M., Zhang, J., & Khan, M. W. (2016). Practicality of marine protected areas-Can there be solutions for the River Indus delta?. *Estuarine, Coastal and Shelf Science*, *183*, 349-359.

Kirchhofer, A. (2002). The role of legislation, institutions and policy making in fish conservation in Switzerland: past, present and future challenges. *Conservation of Freshwater Fishes: Options for the Future*, 389-401.

Kling GW, Hayhoe K, Johnson LB, Magnuson JJ, Polasky S, Robinson SK, Shuter BJ, Wander MM, Wuebbles DJ, Zak DR, Lindroth RL, Moser SC, Wilson ML (2003) Confronting climate change in the great lakes region: impacts on our communities and ecosystems. Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, DC-USA. Retrieved 10/07/2018 from https://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/greatlakes_final.pdf

Koehn, J. D., Hobday, A. J., Pratchett, M. S., & Gillanders, B. M. (2011). Climate change and Australian marine and freshwater environments, fishes and fisheries: synthesis and options for adaptation. *Marine and Freshwater Research*, *62*(9), 1148-1164. DOI- https://doi.org/10.1071/MF11139

Krajnc, D., Glavic, P. (2005). A model for integrated assessment of sustainable development. *Resource Conservation Recycling* 43, 189–208. DOI- https://doi.org/10.1016/j.resconrec.2004.06.002

Kristensen, P. (2004). The DPSIR framework. *National Environmental Research Institute, Denmark*, *10*. Retrieved 10/07/2018 from https://wwz.ifremer.fr/dce/content/download/69291/913220/file/DPSIR.pdf

Kundzewicz, Z. W., Mata, L. J., Arnell, N. W., Döll, P., Jimenez, B., Miller, K., ... & Shiklomanov, I. (2008). The implications of projected climate change for freshwater resources and their management. *Hydrological Sciences Journal*, 53 (1). 3-10. DOI- https://doi.org/10.1623/hysj.53.1.3

Lehtonen, H. (1996). Potential effects of global warming on northern European freshwater fish and fisheries. *Fisheries Management and Ecology*, *3*(1), 59-71. DOI- https://doi.org/10.1111/j.1365-2400.1996.tb00130.x

Lempert, R., Nakicenovic, N., Sarewitz, D., & Schlesinger, M. (2004). Characterizing climate-change uncertainties for decision-makers. An editorial essay. *Climatic Change*, *65*(1-2), 1-9.

Lempert, R. J., Popper, S. W., Kalra, N., Fischbach, J. R., Bankes, S. C., & McInerney, D. J. (2013). Making Good Decisions Without Predictions: Robust Decision Making for Planning Under Deep Uncertainty: RAND Corporation. Santa Monica, CA. https://www.rand.org/pubs/research_briefs/RB9701.html.

Lorenzen, K. (2014). Understanding and managing enhancements: why fisheries scientists should care. *Journal of Fish Biology*, *85*(6), 1807-1829. DOI- https://doi.org/10.1111/jfb.12573

Luck, G. W., Harrington, R., Harrison, P. A., Kremen, C., Berry, P. M., Bugter, R., ... & Haslett, J. R. (2009). Quantifying the contribution of organisms to the provision of ecosystem services. *Bioscience*, *59*(3), 223-235.

Lynch, A. J., Cooke, S. J., Deines, A. M., Bower, S. D., Bunnell, D. B., Cowx, I. G., ... & Rogers, M. W. (2016). The social, economic, and environmental importance of inland fish and fisheries. *Environmental Reviews*, *24*(2), 115-121. DOI- https://doi.org/10.1139/er-2015-0064

Lynch, A. J., Myers, B. J., Chu, C., Eby, L. A., Falke, J. A., Kovach, R. P., ... & Whitney, J. E. (2016). Climate change effects on North American inland fish populations and assemblages. *Fisheries*, *41*(7), 346-361. DOI- https://doi.org/10.1080/03632415.2016.1186016

Lynch, A. J., Varela-Acevedo, E., & Taylor, W. W. (2015). The need for decision-support tools for a changing climate: application to inland fisheries management. *Fisheries Management and Ecology*, *22*(1), 14-24. DOI- https://doi.org/10.1111/fme.12013

Maas-Hebner, K. G., Schreck, C., Hughes, R. M., Yeakley, J. A., & Molina, N. (2016). Scientifically defensible fish conservation and recovery plans: Addressing diffuse threats and developing rigorous adaptive management plans. *Fisheries*, *41*(6), 276-285. DOI- https://doi.org/10.1080/03632415.2016.1175346

Malm, A., & Hornborg, A. (2014). The geology of mankind? A critique of the Anthropocene narrative. *The Anthropocene Review*, *1*(1), 62-69.

Maes, J., Teller, A., Erhard, M., Liquete, C., Braat, L., Berry, P., ... Paracchini, M. L. (2013). Mapping and Assessment of Ecosystems and their Services. *An analytical framework for ecosystem assessments under action*, *5*, 1-58. European Commission, Joint Research Centre, Institute for Environment and Sustainability- Luxembourg. Retrieved 10/07/2018 from https://www.researchgate.net/profile/Joachim_Maes2/publication/274256807

Martins, E. G., Hinch, S. G., Patterson, D. A., Hague, M. J., Cooke, S. J., Miller, K. M., ... & Farrell, A. P. (2011). Effects of river temperature and climate warming on stock-specific survival of adult migrating Fraser River sockeye salmon (Oncorhynchus nerka). *Global Change Biology*, *17*(1), 99-114. DOI- https://doi.org/10.1111/j.1365-2486.2010.02241.x

Mattas, C., Voudouris, K. S., & Panagopoulos, A. (2014). Integrated Groundwater Resources Management Using the DPSIR Approach in a GIS Environment

Context: A Case Study from the Gallikos River Basin, North Greece. *Water*, *6*(4), 1043-1068.

Matthews, T. K., Wilby, R. L., & Murphy, C. (2017). Communicating the deadly consequences of global warming for human heat stress. *Proceedings of the National Academy of Sciences*, *114*(15), 3861-3866. DOI- https://doi.org/10.1073/pnas.1617526114

Maurstad, A., Dale, T., & Bjørn, P. A. (2007). You wouldn't spawn in a septic tank, would you?. *Human Ecology*, *35*(5), 601-610. DOI 10.1007/s10745-007-9126-5

Maxim, L., Spangenberg, J. H., & O'Connor, M. (2009). An analysis of risks for biodiversity under the DPSIR framework. *Ecological Economics*, *69*(1), 12-23. DOI- https://doi.org/10.1016/j.ecolecon.2009.03.017

McIntyre, P. B., Jones, L. E., Flecker, A. S., & Vanni, M. J. (2007). Fish extinctions alter nutrient recycling in tropical freshwaters. *Proceedings of the National Academy of Sciences*, *104*(11), 4461-4466. DOI- https://doi.org/10.1073/pnas.0608148104

McIntyre, P. B., Liermann, C. A. R., & Revenga, C. (2016). Linking freshwater fishery management to global food security and biodiversity conservation. *Proceedings of the National Academy of Sciences*, *113*(45), 12880-12885. DOI- https://doi.org/10.1073/pnas.1521540113

Millennium Ecosystem Assessment, (2003). Millennium Ecosystem Assessment (MA): Strengthening Capacity to Manage Ecosystems Sustainably for Human Well-Being- A Framework for Assessment. Pp. 245. *World Resources Institute*. Island Press: Washington, D.C., United States.

Meyer, J. L., Sale, M. J., Mulholland, P. J., & Poff, N. L. (1999). Impacts of climate change on aquatic ecosystem functioning and health 1. *JAWRA Journal of the American Water Resources Association*, *35*(6), 1373-1386. DOI- https://doi.org/10.1111/j.1752-1688.1999.tb04222.x

Midway, S. R., Wagner, T., Zydlewski, J. D., Irwin, B. J., & Paukert, C. P. (2016). Transboundary fisheries science: Meeting the challenges of inland fisheries management in the 21st Century. *Fisheries*, *41*(9), 536-546. DOI- https://doi.org/10.1080/03632415.2016.1208090

Mohanty, B., Mohanty, S., Sahoo, J., & Sharma, A. (2010). Climate change: impacts on fisheries and aquaculture. In *Climate change and variability*. InTech.

Mooney H, Larigauderie A, Cesario M. (2009). Biodiversity, climate change, and ecosystem services. Current Opinion in Environmental Sustainability, 1, 46–54.

Morrongiello, J. R., Beatty, S. J., Bennett, J. C., Crook, D. A., Ikedife, D. N., Kennard, M. J., ... & Rayner, T. (2011). Climate change and its implications for Australia's freshwater fish. *Marine and Freshwater Research*, *62*(9), 1082-1098. DOI- https://doi.org/10.1071/MF10308

Mote, P., Snover, A. K., Capalbo, S., Eigenbrode, S. D., Glick, P., Littell, J., ... & Reeder, S. (2014). Ch. 21: Northwest. *Climate Change Impacts in the United States: The Third National Climate Assessment, JM Melillo, Terese (TC) Richmond, and GW Yohe, Eds., US Global Change Research Program*, 487-513. DOI- 10.7930/J0J1012N.

Myers, B. J., Lynch, A. J., Bunnell, D. B., Chu, C., Falke, J. A., Kovach, R. P., ... & Paukert, C. P. (2017). Global synthesis of the documented and projected effects of climate change on inland fishes. *Reviews in Fish Biology and Fisheries*, *27*(2), 339-361. DOI- 10.1007/s11160-017-9476-z

Natugonza, V., Ogutu-Ohwayo, R., Musinguzi, L., Olokotum, M., Naigaga, S., & Kitabona, J. (2016). Implications of climate warming for hydrology and water balance of small shallow lakes: A case of Wamala and Kawi, Uganda. *Aquatic Ecosystem Health & Management*, *19*(4), 327-335. DOI- https://doi.org/10.1080/14634988.2016.1142167

Nelson, E. J., Kareiva, P., Ruckelshaus, M., Arkema, K., Geller, G., Girvetz, E., ... & Saunders, M. (2013). Climate change's impact on key ecosystem services and the human well-being they support in the US. *Frontiers in Ecology and the Environment*, *11*(9), 483-893.

OECD, (1993). OECD core set of indicators for environmental performance reviews A synthesis report by the Group on the State of the Environment, OCDE/GD (93)179, Environment Monographs No. 83. Paris. Retrieved 10/07/2018 from http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=OCDE/GD(93)179&docLanguage=En

Osborne, M. (2004). *River at risk: the Mekong and water politics of China and Southeast Asia*. Longueville Media: Haberfield NSW, Australia.

Palmer, M. A., Reidy Liermann, C. A., Nilsson, C., Flörke, M., Alcamo, J., Lake, P. S., & Bond, N. (2008). Climate change and the world's river basins: anticipating management options. *Frontiers in Ecology and the Environment*, *6*(2), 81-89.

Paukert, C. P., Glazer, B. A., Hansen, G. J., Irwin, B. J., Jacobson, P. C., Kershner, J. L., ... & Lynch, A. J. (2016). Adapting inland fisheries management to a changing climate. *Fisheries*, *41*(7), 374-384. DOI- https://doi.org/10.1080/03632415.2016.1185009

Paukert, C. P., Glazer, B. A., Hansen, G. J., Irwin, B. J., Jacobson, P. C., Kershner, J. L., ... & Lynch, A. J. (2016). Adapting inland fisheries management to a changing climate. *Fisheries*, *41*(7), 374-384. DOI- https://doi.org/10.1080/03632415.2016.1185009

Perrings, C. (2005). Mitigation and adaptation strategies for the control of biological invasions. Ecological economics, 52(3), 315-325.

Pittock, J., Hansen, L. J., & Abell, R. (2008). Running dry: freshwater biodiversity, protected areas and climate change. *Biodiversity*, *9*(3-4), 30-38. DOI- https://doi.org/10.1080/14888386.2008.9712905

Poesch, M. S., Chavarie, L., Chu, C., Pandit, S. N., & Tonn, W. (2016). Climate change impacts on freshwater fishes: a Canadian perspective. *Fisheries*, *41*(7), 385-391. DOI- https://doi.org/10.1080/03632415.2016.1180285

Poff, N. L., Olden, J. D., & Strayer, D. L. (2012). Climate change and freshwater fauna extinction risk. In *Saving a Million Species* (pp. 309-336). Island Press/Center for Resource Economics: Washington, D.C., United States.

Preston, S. M. and Raudsepp-Hearne, C. (2017) Completing and Using Ecosystem Service Assessment for Decision-Making: An Interdisciplinary Toolkit for Managers and Analysts (2017). Retrieved 13/08/2018 from https://climate-adapt.eea.europa.eu/metadata/tools/completing-and-using-ecosystem-service-assessment-for-decision-making-an-interdisciplinary-toolkit-for-managers-and-analysts-1

Priti Sanga, N., & Kumar Ranjan, R. (2014). Natural resource management in changing climate–reflections from indigenous Jharkhand. *World Journal of Science, Technology and Sustainable Development*, *11*(2), 117-133. DOI- https://doi.org/10.1108/WJSTSD-10-2013-0040

Punt, A. E., A'mar, T., Bond, N. A., Butterworth, D. S., de Moor, C. L., De Oliveira, J. A., ... & Szuwalski, C. (2013). Fisheries management under climate and environmental uncertainty: control rules and performance simulation. *ICES Journal of Marine Science*, *71*(8), 2208-2220.

Quigley, J. T., & Harper, D. J. (2006). Effectiveness of fish habitat compensation in Canada in achieving no net loss. *Environmental Management*, *37*(3), 351-366.

Rahel, F. J., Bierwagen, B. & Taniguchi, Y. (2008). Managing aquatic species of conservation concern in the face of climate change and invasive species. *Conservation Biology* 22, 551–561. DOI- https://doi.org/10.1111/j.1523-1739.2008.00953.x

Ramalho, C., Will, A., Macleod, J., & van Zyll de Jong, M. (2014). Exploring the Sustainability of Drinking Water Systems in Newfoundland and Labrador: A Scoping Document. Corner Brook, Canada.

Rana, K. J., Grainger, R., & Crispoldi-Hotta, A. (1998). Current methods and constraints for monitoring production from inland capture fisheries and aquaculture. *Inland Fishery Enhancements*, *3*(374), 169.

Rapport D, Friend A (1979). Towards a comprehensive framework for environmental statistics: a stress response approach. Statistics Canada catalogue 11-510. Minister of Supply and Services Canada: Ottawa- Canada.

Reed, M. S., Fraser, E. D., & Dougill, A. J. (2006). An adaptive learning process for developing and applying sustainability indicators with local communities. *Ecological Economics*, *59*(4), 406-418. DOI- https://doi.org/10.1016/j.ecolecon.2005.11.008

Reeves, A. (2016, July 05). Here's why a warming climate means new habitats for bass. *TVO*. Retrieved 29/05/2018 from https://tvo.org/article/current-affairs/heres-why-a-warming-climate-means-new-habitats-for-bass

Reist, J. D., Wrona, F. J., Prowse, T. D., Dempson, J. B., Power, M., Köck, G., ... & Tallman, R. F. (2006). Effects of climate change and UV radiation on fisheries for arctic freshwater and anadromous species. *AMBIO: A Journal of the Human Environment*, *35*(7), 402-410. DOI- https://doi.org/10.1579/0044-7447

Reist, J. D., Wrona, F. J., Prowse, T. D., Dempson, J. B., Power, M., Köck, G., ... & Tallman, R. F. (2006). Effects of climate change and UV radiation on fisheries for arctic freshwater and anadromous species. *AMBIO: A Journal of the Human Environment*, *35*(7), 402-410. DOI- https://doi.org/10.1579/0044-7447

Rieman, B. E., Isaak, D., Adams, S., Horan, D., Nagel, D., Luce, C., & Myers, D. (2007). Anticipated climate warming effects on bull trout habitats and populations across the interior Columbia River basin. *Transactions of the American Fisheries Society*, *136*(6), 1552-1565.

Rosenberg, N. J. (1988). The Greenhouse Effect, Climatic Change and Ecosystems. *Bulletin of the American Meteorological Society*, 69 (2), 194-196. Retrieved from http://www.jstor.org/stable/26225888

Rounsevell, M. D. A., Dawson, T. P., & Harrison, P. A. (2010). A conceptual framework to assess the effects of environmental change on ecosystem services. *Biodiversity and Conservation*, *19*(10), 2823-2842. DOI 10.1007/s10531-010-9838-5

Ruby, P., & Ahilan, B. (2018). An overview of climate change impact in fisheries and aquaculture. *Climate Change*, *4*(13), 87-94.

Sala, O. E., Chapin, F. S., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., ... & Leemans, R. (2000). Global biodiversity scenarios for the year 2100. *Science*, *287*(5459), 1770-1774. DOI: 10.1126/science.287.5459.1770

Sam Ath, L., Purba, H., Keophimphone, V., Riti Anak Rantty, I., Toe, A., Libunao, R. R., ... & Van Hao, T. (2013). Improving fisheries and habitat management, climate change adaptation and social well-being in Southeast Asia: the SEAFDEC-Sida project in focus. Secretariat, Southeast Asian Fisheries Development Center. Retrieved 05/07/2018 from http://repository.seafdec.org/bitstream/handle/20.500.12066/913/SP11-2%20fisheries%20habitat%20management.pdf?sequence=1

Schindler, D. W. (2001). The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium. *Canadian Journal of Fisheries and Aquatic Sciences*, *58*(1), 18-29. DOI- https://doi.org/10.1139/f00-179

Schröter, D., Cramer, W., Leemans, R., Prentice, I. C., Araújo, M. B., Arnell, N. W., ... & Anne, C. (2005). Ecosystem service supply and vulnerability to global change in Europe. *Science*, *310*(5752), 1333-1337. DOI: 10.1126/science.1115233

Singh, R. K., Murty, H. R., Gupta, S. K., & Dikshit, A. K. (2009). An overview of sustainability assessment methodologies. *Ecological Indicators*, *9*(2), 189-212. DOI- https://doi.org/10.1016/j.ecolind.2011.01.007

Smeets, E., & Weterings, R. (1999). *Environmental indicators: Typology and overview* (p. 19). European Environment Agency: Copenhagen- Denmark.

Speedy, A. W. (2003). Global production and consumption of animal source foods. *The Journal of Nutrition*, 133(11), 4048S-4053S. DOI- https://doi.org/10.1093/jn/133.11.4048S

Stiassny, M. L. (1996). An overview of freshwater biodiversity: with some lessons from African fishes. *Fisheries*, *21*(9), 7-13. DOI- https://doi.org/10.1577/1548-8446

Strayer, D. L., & Dudgeon, D. (2010). Freshwater biodiversity conservation: recent progress and future challenges. *Journal of the North American Benthological Society*, *29*(1), 344-358. DOI: 10.1899/08-171.1

Strayer, D. L., & Dudgeon, D. (2010). Freshwater biodiversity conservation: recent progress and future challenges. *Journal of the North American Benthological Society*, *29*(1), 344-358. DOI: 10.1899/08-171.1

Sumaila, U. R., Bellmann, C., & Tipping, A. (2016). Fishing for the future: An overview of challenges and opportunities. *Marine Policy*, *69*, 173-180. DOI- https://doi.org/10.1016/j.marpol.2016.01.003

Sun, S., Wang, Y., Liu, J., Cai, H., Wu, P., Geng, Q., & Xu, L. (2016). Sustainability assessment of regional water resources under the DPSIR framework. *Journal of Hydrology*, *532*, 140-148. DOI- https://doi.org/10.1016/j.jhydrol.2015.11.028

Suuronen, P., & Bartley, D. M. (2014). Challenges in managing inland fisheries—using the ecosystem approach. *Boreal Environment Research*, 19: 245–255. https://helda.helsinki.fi/bitstream/handle/10138/228597/ber19-3-245.pdf?sequence=1

The Nature Conservancy Great Lakes Program. (1994). The conservation of biological diversity in the Great Lakes ecosystem: issues and opportunities. Chicago-USA.

Timmerman, J. G., Beinat, E., Termeer, C. J. A. M., & Cofino, W. P. (2011). Developing transboundary river basin monitoring programmes using the DPSIR indicator framework. *Journal of Environmental Monitoring*, *13*(10), 2808-2818. DOI: 10.1039/C1EM10092K

UNEP (2007). Global Environment Outlook (GEO) 4 Environment for Development. United Nations Environmental Programme (UNEP), Malta Program Press Company Ltd, Valletta, Malta.

UNEP (2014) Guidelines for conducting Integrated Environmental Assessments. Chapter (3); Integrated Analysis of Environmental Trends and Policy Responses. Retrieved 12/07/2018 from https://wedocs.unep.org/bitstream/handle/20.500.11822/16775/IEA_2017_02_17_LivingDocument.pdf?sequence=1&isAllowed=y

UNEP (United Nations Environment Program). (1994). Convention on biological diversity. Text and annexes. Gland, Switzerland.

Uppanunchai, A., Apirumanekul, C., & Lebel, L. (2015). Planning for production of freshwater fish fry in a variable climate in Northern Thailand. *Environmental management*, *56*(4), 859-873. DOI 10.1007/s00267-015-0547-4

Van der Zaag, P. (2005). Integrated Water Resources Management: Relevant concept or irrelevant buzzword? A capacity building and research agenda for Southern Africa. *Physics and Chemistry of the Earth, Parts A/B/C*, *30*(11-16), 867-871. DOI- https://doi.org/10.1016/j.pce.2005.08.032

Vass, K. K., Das, M. K., Srivastava, P. K., & Dey, S. (2009). Assessing the impact of climate change on inland fisheries in River Ganga and its plains in India. *Aquatic Ecosystem Health & Management*, *12*(2), 138-151. DOI- https://doi.org/10.1080/14634980902908746

Wainwright, T. C., & Weitkamp, L. A. (2013). Effects of climate change on Oregon Coast coho salmon: habitat and life-cycle interactions. *Northwest Science*, *87*(3), 219-242. DOI- https://doi.org/10.3955/046.087.0305

Welcomme, R. L. (2002). An evaluation of tropical brush and vegetation park fisheries. *Fisheries Management and Ecology*, 9, 175–188. DOI- https://doi.org/10.1046/j.1365-2400.2002.00292.x

Welcomme, R. L., Cowx, I. G., Coates, D., Béné, C., Funge-Smith, S., Halls, A., & Lorenzen, K. (2010). Inland capture fisheries. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1554), 2881-2896. DOI: 10.1098/rstb.2010.0168

Whitfield, A. K., & Cowley, P. D. (2010). The status of fish conservation in South African estuaries. *Journal of Fish Biology*, *76*(9), 2067-2089. DOI- https://doi.org/10.1111/j.1095-8649.2010.02641.x

Whitney, J. E., R. Al-Chokhachy, D. B. Bunnell, C. A. Caldwell, S. J. Cooke, E. J. Eliason, M. Rogers, A. J. Lynch, and C. P. Paukert. (2016). Physiological basis of climate change impacts on North American inland fishes. *Fisheries*, 41, (7)332–345. DOI- https://doi.org/10.1080/03632415.2016.1186656

Whitney. (2016). Climate change effects on North American inland fish populations and assemblages. *Fisheries,* 41, 346–361. DOI- https://doi.org/10.1080/03632415.2016.1186016

Wilby, R. L., and coauthors. (2010). Evidence needed to manage freshwater ecosystems in a changing climate: turning adaptation principles into practice. *Science of the Total Environment*, 408(19), 4150–4164. DOI- https://doi.org/10.1016/j.scitotenv.2010.05.014

Williams, J. W., & Jackson, S. T. (2007). Novel climates, no-analog communities, and ecological surprises. *Frontiers in Ecology and the Environment*, *5*(9), 475-482.

World Bank (2010) World Development Report 2010: Development and Climate Change. The World Bank, Washington, DC, USA, 424 pp.

WWF (2014). WWF living planet report (2014). (World Wildlife Fund) Retrieved 29/05/2018 from https://www.documentcloud.org/documents/1306490-wwf-living-planet-report-2014-summary.html

Xenopoulos, M. A., Lodge, D. M., Alcamo, J., Märker, M., Schulze, K., & Van Vuuren, D. P. (2005). Scenarios of freshwater fish extinctions from climate change and water withdrawal. *Global Change Biology*, *11*(10), 1557-1564. DOI- https://doi.org/10.1111/j.1365-2486.2005.001008.x

Zhao, Y., Gozlan, R. E., & Zhang, C. (2015). *Current state of freshwater fisheries in China*. Wiley-Blackwell: Oxford-UK.

Naylor, R. L., Goldburg, R. J., Primavera, J. H., Kautsky, N., Beveridge, M. C., Clay, J., ... & Troell, M. (2000). Effect of aquaculture on world fish supplies. *Nature*, *405*(6790), 1017.

WWF. (2016). *Living Planet: Report 2016: Risk and Resilience in a New Era*. World wide fund for nature: Gland, Switzerland.

Soliman, A. (2014). Using individual transferable quotas (ITQs) to achieve social policy objectives: A proposed intervention. *Marine Policy*, *45*, 76-81.

Shen, G., & Heino, M. (2014). An overview of marine fisheries management in China. *Marine Policy*, *44*, 265-272.