Chapter 5

The Potential Impacts of Global Climatic Changes and Dams on Amazonian Fish and Their Fisheries

Carlos Edwar de Carvalho Freitas,
Alexandre A. F. Rivas, Caroline Pereira Campos,
Igor Sant'Ana, James Randall Kahn,
Maria Angélica de Almeida Correa and
Michel Fabiano Catarino

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/54549

1. Introduction

The Amazon River Basin, which encompasses the world's largest remaining tropical rainforest, has the highest diversity of fish species of any region in the world [1]. Some of these species represent highly abundant fish stocks that have supported an important fishery for many decades, or many centuries if the history prior to European colonization is included. The importance of fishing in the Amazon River Basin can easily be observed from the high fish consumption, which is mainly attributed to people who live in rural areas near rivers and lakes (Table 1). Regardless of this importance for food, there is no integrative strategy for fishery management, and the activity in this basin as a whole is highly vulnerable to externalities, including those resulting from environmental changes and man-made interventions.

There is a consensus that fishery production is directly related to biological productivity, which is a function of a set of environmental characteristics in the aquatic system. The majority of the Rio Amazonas and its tributaries are accompanied by large floodplains, which is where most of the biological production occurs. A key factor for biological production in the floodplains of large Amazonian rivers is the flood pulse [9], which generates tremendous variation in the input of nutrients over the course of the year, primarily at river headwaters located in the pre-Andean areas, such as Madeira, Purus, Juruá, and Solimões. The flood pulse is the driving element that structures the landscape of the floodplains adjacent to the river channels, forming a mobile ecotone that is referred to as ATTZ or the aquatic-terrestrial transition zone [9].

Reference	Sub-basin	Social group	g/per capita.day	Kg/per capita.year
[2]	Rio Negro	urban	53.95	19.69
[3]	Rio Negro	urban	121.70	44.42
[4]	Rio Amazonas	rural	369.00	135.00
[5]	Rio Solimões	rural	510.00 to 600.00	186.00 to 219.00
[6]	Rio Solimões and Rio Japurá	rural	509.00 to 805.00	186.00 to 294.00
[7]	Rio Madeira	rural	243.00	88.00
[8]	Rio Amazonas	rural	511.00 to 643.00	187.00 to 235.00

Table 1. Fish consumption in the Amazon River Basin.

The Amazonian hydrological cycle is annual and quite predictable. The flood intensity and timing is controlled by several factors, including those that act on a global scale. The cyclical phenomenon of warming in the Pacific Ocean near the cost of Peru, termed *El Niño*, is related to severe drought in the Amazon Basin. Alternatively, *La Niña* is associated with strong floods. The simultaneous occurrence of other climatic phenomena, such as the warming of the Tropical North Atlantic Ocean, has been used to explain extreme climatic events [10].

Despite the lack of models describing the relationship between flood intensity and timing and fishing success, the life strategy of many species of Amazonian fish is synchronized with the hydrological cycle. For example, several species of Characiforms, including *Colossoma macropomum*, *Brycon amazonicus*, *Prochilodus nigricans*, *Semaprochilodus insignis*, *S. taenirus*, *Piaractus brachypomum* and others, begin their reproductive migration at the beginning of the rainy season when the waters begin flooding [11, 12, 13]. This life strategy was most likely developed to ensure the colonization of the floodplain with newly hatched larvae. The availability of food and places of refuge in the colonized floodplain may determine the strength of the annual recruitment of these species.

There is ample evidence that the Earth's climate is changing more rapidly now than it has in the past [14], with potential effects on the Amazon basin [15, 16]. These effects include physical alterations and changes in nutrient flow [14]. Although uncertainties associated with how local climates change in response to global climate change exist, global circulation models employed by the Intergovernmental Panel on Climate Change (IPCC) have found an increased likelihood of a significant increase in the mean global temperature [14]. A rise in sea level is also predicted, with estimates varying between 0.75 m to 1.90 meters by the end of twenty-first century [17]. Other environmental changes in freshwater systems, such as stratification, productivity reduction and acidification, have no consistent patterns. These changes are very difficult to generalize based on the available evidence; however, there is a

http://dx.doi.org/10.5772/54549

consensus that the impact on fish will be species-specific, that is directly related to the biological characteristics of each species.

Nevertheless, the effects on fisheries should be a result of a series of effects that start at the organism level. At an individual level, all fish have an optimal thermal interval that is limited on the upper and lower boundaries by their critical thermal maxima and minima, respectively [18], thus reducing the analysis of the warming effects. Therefore, fish exposed to temperatures within the sub-lethal interval, excluding the optimal thermal interval, may be affected by warming, and the consequences of this temperature effect should be evident by physiological responses. The high energetic cost necessary to compensate for these unfavorable environmental conditions may affect the growth rates or reproduction success of the fish (Figure 1). Realistically, general effects from water warming can be expected. Because biochemical reaction rates are a function of body temperature, all aspects of an individual fish's physiology, including growth, reproduction and activity, are directly influenced by changes in temperature [19].

When the environment changes, these temperature effects should continue to increase and may be perceptible at the population and community levels. Although different species are affected by environmental change in different ways, the abundance patterns of the entire community, and thus the fishing production, should be influenced (Figure 1).

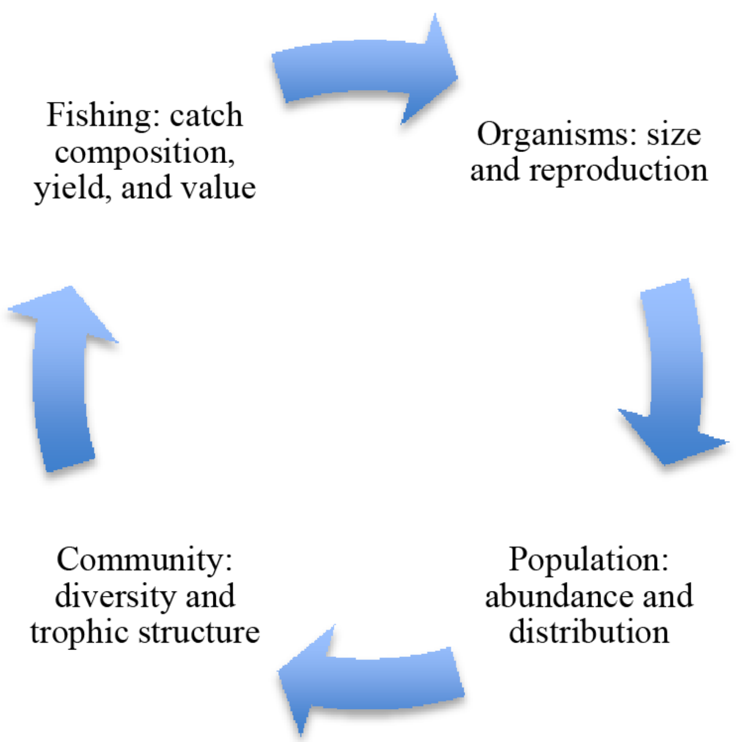


Figure 1. The effects of global climatic changes on different levels.

Dams cause local changes at the sub-basin level but also have the potential to exhibit regional effects. In essence, the impact of dams on the hydrological river cycle, which primarily involves flood timing, is the most important effect of change in freshwater fisheries because the flood regime is the most important determining force in Neotropical rivers [20]. Dam construction can affect environments and fisheries by changing the timing and quantity of river flows; altering the water temperature, nutrient and sediment transport; reducing adjacent floodplains and other wetlands; and blocking fish migrations.

Currently, there is a large proliferation of hydroelectric dams within the Amazon region. At the western boundary near the Andean and Pre-Andean areas, there are plans for 151 new hydroelectric dams with greater than 2 MW of power over the next 20 years, which is more than a 300% increase [21]. Similarly, in the Brazilian region near the south and southeast boundaries of the Amazon, there are several hydroelectric dam projects that have the potential to completely fragment the river basins with headwaters on the Brazilian Plateau. Similar to climate change, the impact of dams should be associated with the life strategies of different fish species.

The most important species captured by small-scale fisheries in the Amazon basin belong to three groups: Characiforms, which are primarily from the Prochilodontidae, Characidae, and Serrasalmidae families; Siluriforms, which are primarily from the Pimelodidae family and include piramutaba (*Brachyplatystoma vailantii*), dourada (*B. rouseauxii*) and piraíba (*B. filamentosum* and *B. capapretum*); and Perciforms, which are primarily from the genus *Cichla*. Over evolutionary time, members of these groups have developed specific life strategies designed to optimize the survival of Amazonian environmental conditions. Alterations induced by global changes or man-made interventions may directly influence these strategies, with negative effects on both the recruitment and stock abundance of these species, as well as on the socio-economic conditions of the Amazonian people that exploit these fish stocks for food and income.

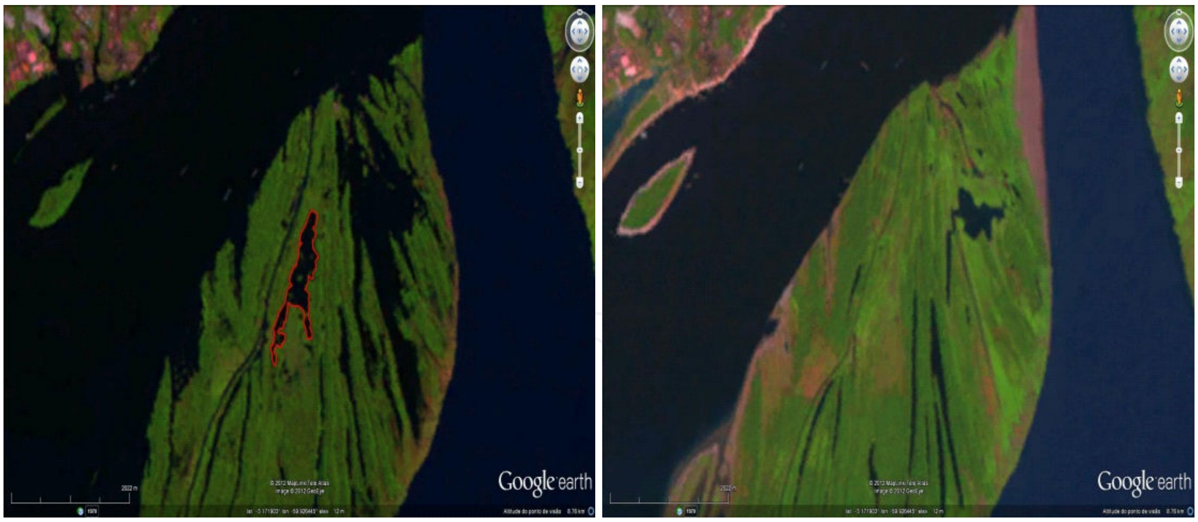
Therefore, the goals of this chapter are as follows:

1. Review the main scenarios for environmental alterations in the Amazon Basin, which is predicted to be a function of global climatic changes and dams.
2. Identify the potential impacts of different scenarios of environmental alterations in the Amazon Basin on Amazonian freshwater fish populations.
3. Identify the consequences of the predicted impacts on the Amazonian freshwater fish populations, taking into account the main characteristics of the population dynamics.
4. Illustrate the potential social and economic consequences for the local and regional fisheries and the people who depend on these fisheries.

2. Global climatic changes and dams: What we can expect and what are the potential effects

Despite the uncertainties at the local level, it is highly likely that there will be more frequent occurrences of extreme climatic events. Most of the global climate models (GCMs) proposed by the IPCC [14] project significant Amazonian drying during the 21st century. Pacific sea surface temperature (SST) variation, which is dominated by the El Niño–Southern Oscillation (ENSO), is the main driving force for wet-season rainfall. However, dry-season rainfall is strongly influenced by the Tropical Atlantic north-south SST gradient. Therefore, an intensification of this gradient from the warming of northern SSTs relative to those of the south would move the Inter-Tropical Convergence Zone north and strengthen the Hadley Cell circulation. This change would enhance the duration and intensity of the dry season in much of southern and eastern Amazonia, which already has occurred in 2005. Studies indicated that the most extreme droughts in Amazonia were a result of the strong events of the El Niño-Southern Oscillation (ENSO), the large temperature increase of the sea surface in the Tropical North Atlantic or a combination of these events [22]. Changes in precipitation during the dry season are likely the most critical determinant of the climatic fate of the Amazon [14].

These extreme droughts, even if short in duration, can be catastrophic for aquatic organisms because of the strong reduction in the area of the aquatic environments. Floodplain lakes are the most impacted, and the areas of these lakes can be reduced by several orders of magnitude (Figure 2). Although several species of fish are able to relocate to the river channel during the dry season, some lake resident species remain in the lakes and are unable to survive if the drought is severe. Some studies have observed that fish assemblages seemed to recover rapidly from normal drought seasons [23], but there are indications that extreme droughts occasionally alter fish assemblages. Some species that are vulnerable to these catastrophic events may disappear at a local level [23].



(a) (b)

Figure 2. A floodplain area of the Rio Amazonas during the flood season (A) and dry season (B) when an extreme drought occurred.

Another likely climatic change is global warming [14]. Over the next two decades, a warming of approximately 0.2°C per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been maintained at the levels present in the year 2000, a further warming of approximately 0.1°C per decade would be expected [14]. This warming represents an increase of 1-7ºC in the mean global temperature within the next one hundred years.

Freshwater fish may explore habitats within an optimal thermal interval and thermo-regulate behaviorally and physiologically. Temperature tolerance ranges are species-specific and range from stenothermal species that support only a narrow thermal range to eurythermal species that are able to live in a wide thermal range. Fish populations subjected to changing thermal regimes may increase or decrease in abundance, experience range expansions or contractions or face extinction [19]. There is also an inverse relationship between the temperature and concentration of dissolved oxygen in water. Thus, an increase in the temperature can exacerbate the hypoxia or anoxia conditions naturally observed in some lentic habitats of freshwater fish.

A direct consequence of global warming is a rise in sea level. Despite the uncertainties related to the dynamics of ice sheets and glaciers, there are models that predict a rise in sea level, which were summarized previously [14]. One model proposed a relationship between global sea level variations and the global mean temperature and predicts a rise in sea level ranging from 75 to 190 cm for the period 1990-2100 [17]. However, some scenarios [14] predict a rise of 4.0 meters (Table 2).

What are the potential effects of a rise in sea level for the Amazon Basin? With regard to its physical characteristics, we can anticipate that the sea will be a hydraulic barrier and will flood areas that are not currently flooded but which are primarily within the floodplain adjacent to the river channel. Other environmental consequences of this barrier can also be expected: a reduction in water flow, an increase in the sedimentation rate and an increase of the flooded area. It is possible that the hydrological cycle will also be affected.

These changes to the hydrological cycle can be magnified by the fragmentation of the environment that will occur as a result of the introduction of hydroelectric dams. We can identify at least four phenomena associated with the introduction of dams:

1. Blockage of the sediment flow in whitewater systems (e.g., Rio Madeira).
2. Change of the flood pulse.
3. Blockage of fish migration.
4. Reduction in oxygen levels both above and below the dams.

Blockage of the sediments might have a large effect on fish communities. Whitewater rivers originate in Pre-Andean areas and are heavily loaded with volcanic soil sediment. The dams act as a barrier and result in a reduction of water speed, thus improving the rate of decantation. The end result is an impoverishment of the river below the dam. Thus, the species that have evolved in the presence of high levels of nutrients will not be able to adapt to the rapid loss in primary productivity that is associated with the reduction of nutrient content. This result will favor a change in the composition of local species and will have serious impacts on fishing activity.

http://dx.doi.org/10.5772/54549

	Temperature change ((C at 2090-2099 relative to 1980-1999)		**Sea level rise (m at 2090-2099 relative to 1980-1999)**
	Best estimate	Likely range	Model-based range excluding future rapid dynamic changes in ice flow
Constant Year 2000 concentration	0.6	0.3 - 0.9	NA
B1 scenario	1.8	1.1 - 2.9	0.18 - 0.38
A1T scenario	2.4	1.4 - 3.8	0.20 - 0.45
B2 scenario	2.4	1.4 - 3.8	0.20 - 0.43
A1B scenario	2.8	1.7 - 4.4	0.21 - 0.48
A2 scenario	3.4	2.0 - 5.4	0.23 - 0.51
A1F1 scenario	4.0	2.4 - 6.4	0.26 - 0.59

Table 2. Projected global average surface warming and associated sea level rise at the end of the 21st century. Source: [14]

Similarly, Amazonian fish species evolved in a system regulated by an annual and predictable flood pulse, developing life strategies to explore the several habitats available during the hydrological cycle. The elimination or change in the timing or duration of this pulse can destroy signals that trigger reproduction and other life cycle events, which will potentially influence fish recruitment.

The blockage of the fish migration can be critical, with significant impacts for some species that participate in long-distance migrations from the estuary to the headwaters of whitewater rivers to spawn. As a result, some populations may be locally extinct.

The fourth phenomenon concerning the fall in oxygen levels is relatively self-explanatory. The large amount of organic material in the reservoirs will remove a great deal of oxygen from a system that is already low in oxygen content due to the water temperature. The synergy between this phenomenon and global warming is quite evident. The results may include the loss of species with less tolerance for low oxygen conditions.

Clearly, these phenomena can be completely integrated and synergistic, and their effects on fish communities can be magnified and strongly disruptive. As is most often the case with multiple sources of environmental stress, the combined stress resulting from several sources is greater than the sum of the individual stresses. This point is emphasized by [21], who stated that the impact of hydroelectric dams in the Amazon Basin should be considered in a broad perspective, including the planned projects of other Amazonian countries, such as Bolivia, Colombia, Ecuador and Peru. The fragmentation of Amazonian rivers originating in Pre-Andean areas may result in severe nutrient depletion of the rivers because the mountains and associated uplands are the main source of sediments that form the basis for the high primary productivity observed in the Amazonian floodplains.

An unavoidable effect of dams is the shift in species composition and abundance. This shift includes the extreme proliferation of some populations and a reduction, or even elimination, of others [25]. The obstacles in the migratory routes, the loss of natural nursery areas placed upstream of dams and the modification of the hydrological regime downstream of dams, in addition to the rheophilic behavior of the community, are factors directly linked to failures in recruitment and the limited distribution of adults in reservoirs [25], which strongly affect fisheries [26].

3. Life strategies of freshwater amazonian fish

In the Amazon Basin, the life strategies associated with migratory and reproductive processes can be employed to distinguish three fish groups. First, groups can be distinguished by their migration length. The fish species that participate in long-distance migrations are from the family Pimelodidae and belong to a unique genus: *Brachyplatystoma rousseauxii*, *B. vailantii*, *B. filamentosum*, *B. capapretum* and *B. platynemum*[13]. These species migrate up to 3,000 km to complete their life cycle. They migrate from the Amazonian estuary to the border of the Andean mountains in Bolivia, Colombia and Peru [27]. The estuary is the nursery area, and the fish remain there approximately one year prior to beginning their migration. The floodplain areas of the Central Amazon Basin are feeding habitats where the immature fish grow up and store fats prior to their reproductive migration toward the Pre-Andean areas [13, 27, 28, 29]. This process is synchronized with the hydrological cycle. The gonads of *B. rousseauxii* are in an advanced stage of development starting at the beginning of the flood season, while *B. flamentosum*, *B. platynemum* and *B. vailantii* show the highest reproductive activity at the end of the flood season [28].

The short-distance migratory species belong to several groups, including Siluriforms such as *Pinirampus pirinampu*, *Calophysus macropterus*, *Hypophthalmus marginatus*, *H. edentates*, *H. fimbriatus*, *Phractocephalus hemiliopterus*, *Pseudoplatystoma punticfer*, *P. fasciatum* and *P. tigrinum* [13, 30, 31]. These species are also called floodplain migratory fish because they participate in short-distance migrations between the main stem of the Amazon River and its tributaries and floodplain lakes. Despite the absence of published studies, evidence from field research indicates that the migrations of this group do not appear to exhibit a pattern associated with reproductive events. Because these fish are predator species, these short-distance migrations have trophic causes and are developed to find prey in general small and medium size characins.

Another short-distance migratory species is a highly diverse group of Characiformes, which are extensively exploited by the small-scale fishing fleet from the Amazon Basin. Species such as *Colossoma macropomum*, *Prochilodus nigricans*, *Semaprochilodus insignis*, *S. taenirus* and several Myleinae and Curimatidae evolved for a life strategy strongly associated with the hydrological cycle of the Amazon Basin [13, 32, 33]. These species build large schools at the beginning of the rainy season and participate short-distance migrations from their feeding habitat, which is generally within black water tributaries, to white water rivers where spawning occurs [13, 32, 33, 34, 35]. The parental schools are very large, containing hundreds of thousands of individuals, and there is no parental care after spawning [13, 36]. Adult fish move toward flooded areas, which are rich in food, aiming to store energy for a new reproductive cycle. There are some differences between the timing of migration for these species; however, the schematic in Figure 3 shows the synchronism with the rainy season when the water starts to rise and the importance of the newly inundated floodplains as a place of refuge and feeding for the young fish [37].

Lastly, there are species that do not need to migrate to complete their life cycle. These fish are a diversified group with species from several orders; however, some cichlids from the genus *Cichla* are highly important for regional fisheries. These cichlids are called peacock bass and are the main target of recreational fisheries that are located primarily in black water rivers. The peacock bass is also a to predator that moves in several environments for trophic reasons [37]. Ornamental fish compose another group of non-migratory species that are exploited by fishing. This group is highly diverse, with species belonging to several orders, including Characiforms, Siluriforms, Perciforms, Osteoglossiforms and Gymnotiforms. In general, these are small sized fish with high levels of endemism.

4. Potential effects of global climatic changes and dams on freshwater amazonian fish

The intensity and direction (positive or negative) of the potential effects of environmental changes will vary among populations and species in the Amazonian fish fauna. Some global scenarios are catastrophic [38], proposing that 75% of global freshwater fish will become extinct before the end of the 21st century due to a reduction in river discharge. Nevertheless, the possible effect is local extinction, which would be a critical event for endemic species. Two species of the small fish *Paracheirodon*, which are exploited as ornamental species, exist in the middle to upper Rio Negro in Brazil and in the upper Rio Orinoco in Colombia and Venezuela. A study conducted at an inter-fluvial palm camp of the Middle Rio Negro found that these two species are rarely observed in the same habitat. The *P. simulans* habitat water temperature ranged from a low of 24.6 to a high of 35.2 ºC, while the *P. axelroldi* habitat temperature varied between 25.1 and 29.9 ºC [39]. The authors propose that because inter-fluvial areas flood as a function of rainfall, a decrease in regional precipitation could alter the hydrologic balance of these wetlands, especially during dry periods, which would lower water levels and increase the water temperature. This scenario would be extremely adverse for *P. simulans*, which exists only in very shallow inter-fluvial areas. A decrease in precipitation could dry out these areas completely, ultimately leading to the local extinction of this species.

At the beginning of rising waters season, the adults move down river from tributaries of black and clear waters to spawning in the turbid and rich environment of white water rivers. After breeding event, these fish move toward the flooded forest for feeding. The larvae are carried by drift toward flooded areas of the floodplain. After six months, when the water starts to recede, large schools of adults and young fish move toward tributaries.

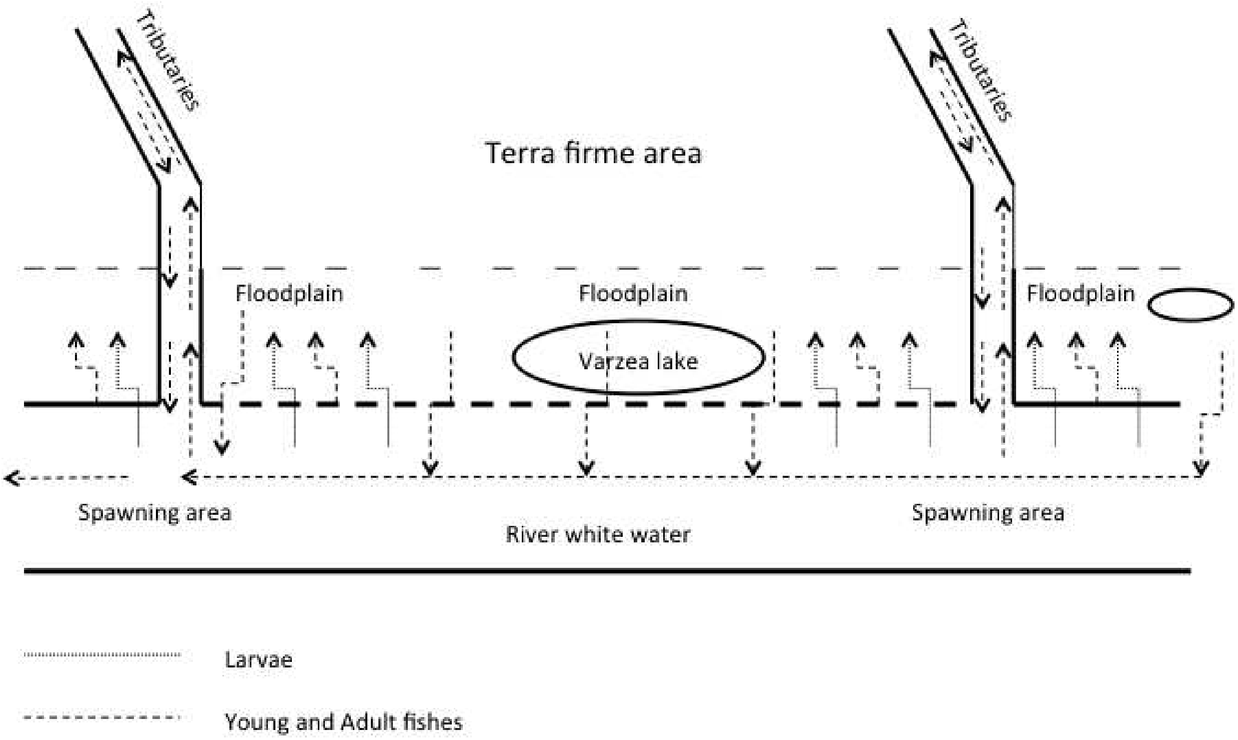


Figure 3. A general description of the Characiforms migrations.

The survivorship or abundance of fish species in a dynamic environment is dependent on three factors: the intensity of change, the velocity at which change will occur and the ability of organisms to adapt in the midst of these changes. Plasticity is a characteristic inherent to each species of fish. However, some common characteristics are useful for classifying the fish into groups and for discussing the most probable effects of environmental changes. For example, the impact of changes in the water temperature should be related to the lethal, sub-lethal and optimal thermal limits of each species. Despite of a scarcity of data on the physiology, life history and behavior of the Amazonian species, some information about population dynamics is available and can be used to hypothesize the effects of the environmental changes resulting from climate change and new dams.

The inverse relationship between temperature and dissolved oxygen in the water may result in an expansion of hypoxia zones. Although the Amazonian fish exhibit a variety of strategies related to oxygen intake in response to hypoxia [40], there are limits to these adaptive strategies that are a result of a long evolutionary time.

Another example of the types of analyses that can be conducted involves the use of the match-mismatch hypothesis (originally proposed by Cushing [41, 42] to describe the relationship between starvation and recruitment), which has clear connections to climate variability. This hypothesis recognizes that early-stage fish need food to survive and grow. It also recognizes that periods of strong food production in the ocean can be variable and are often controlled by climate, which depends on the strength of the wind, the frequency of storms and the amount of heating or fresh water supplied to the surface layers in the ocean. The hypothesis examines the timing match or mismatch between when and where food is available and when and where early-stage fish are able to encounter and consume this food. Assuming that there is a synchrony between the flood pulse and the spawning season of the Amazonian Characiformes, this cycle can be modified by climatic changes with substantial consequences on species that are the most important sources of protein consumption in the Amazon Basin.

In fact, some species or groups of species may be positively affected. A study of the reproduction of fish from the Rio Cuiabá in Upper Pantanal indicated that both the reproductive dynamics and the hydrological regime were closely related. The authors of the study showed that the intense events of floods were positively related with gonadal development of species that participate in long-distance migration and parental care [43].

A potentially useful approach to develop strategies to study the effects of global climate change could be classifying their effects by the type of relationship between the phenomenon and the impact. [44] classified the range of effects that climate change will have on freshwater, estuarine and marine fish into primary, secondary and tertiary categories. These authors found that the primary impacts are climate-related changes that directly affect the behavior, physiology, fitness and survivorship of fish without intermediary causal drivers. Secondary effects are primarily related to changes in the quality or quantity of habitats. Lastly, the tertiary impacts are related to the interactions between several causal factors.

In contrast, impacts from dams are generally related to the fragmentation of the area in which the individual members of a species live, creating obstacles for migration. The decline in the abundance of long-distance migratory species is the most distinct consequence of such filters. The community of these species undergoes seasonal migrations toward spawning habitats located upstream and consequently requires free-flowing stretches of river. Therefore, recruitment success depends on the presence of and accessibility to spawning areas, which are located in the upstream stretches of the main channel and its tributaries, as well as nursery habitats, which are located in flooded areas downstream [25, 45]. The loss of nursery habitat can critically impact several species, including several species of Characins and Perciforms. Dams also alter water temperature and quality [26, 46], which affects the community structure as a whole.

In addition, there are predictable changes in the species composition of the fish assemblages above the dam in the altered environment of the reservoir, and pre-adapted species could become abundant in this location. However, an impoverishment in the fish diversity as a whole would be expected [25, 26]. A study developed to analyze the alterations of the fish communities due to pollution and the damming of highly impacted rivers from Southeast Brazil, which were fragmented and polluted in their upper stretches, and also detected a synergic effect due to these two impact sources [47]. These authors observed a noticeable decrease in species richness in the polluted stretches of the river, with one or two species dominating. However, the artificial control of floods and discharge levels should have direct impacts on recruitment success. An analysis on the influence of the mean annual water level (m), the amplitude (maximum water level of the river in a given year; m) and the flood duration (number of days above 3.5 m; yearly total and for each season; summer and autumn were considered together) on the recruitment of *Prochilodus scrofa* for the fishery conducted at the Itaipu Reservoir and observed that flood duration is more important than flooding amplitude [48].

Table 3 summarizes the effects of global warming, sea level rise and dams on freshwater Amazonian fish, taking into account our level of knowledge. Fish faced with a changing environment must adapt, migrate or perish [19]. In addition to the high level of uncertainty at the species level, some evidence is available to predict that the resulting stress of a temperature increase will affect fauna as a whole, including fish. The effects of the higher energy demand to compensate the stress would start at the physiological level and would include size reduction and reproductive failure. This evolution affects the community structure when the dominant species has more adaptive capacity. Therefore, another possible effect of climate change is the loss of biodiversity through the extinction of specialized or endemic fish species [48]. This pattern of environmental change inducing effects will initiate from a rise in sea level and the introduction of dams.

5. Social and economic effects of climate changes and dams on amazonian fisheries

Fisheries are very important activity worldwide. Gross revenues from marine capture fisheries worldwide are estimated between US$ 80 billion and 85 billion annualy [49]. However, some authors stated that the global marine fisheries are underperforming economically due to overfishing, pollution and habitat degradation [50]. As is the case in many regions of the world, fish are a key source of animal protein, essential amino acids and minerals, mainly for low-income population who live in the Amazon basin [3, 5, 6]. A recent paper examines if marine fisheries and aquaculture can supply fish demand for a growing human population, taking into account climate change [51]. The authors claim that an effective management of fisheries is necessary to assure sustainability for world fish stocks. The authors also called for a reduction in the amount of wild fish employed to produce animal feed.

In general, Brazilian fish production followed the world tendency, with mean rates of growth of 2.48% and 10.82%, for fishing and aquaculture, respectively [52]. Analyzing just Amazonas State, the main producer of fish exclusively from freshwater, we can see that the state follows the same trend of the region, for the last ten years. On average, the Amazonas State contributed 29% of the region's fisheries production.

A closer analysis of the data shed some light on the impacts of environmental changes, as a result of climate changes or dams, on fisheries and its consequences for well being. Figure 5 shows the Amazonas state Gross Domestic Product (GDP) per capita and an index of fish production growth, for the period between 1992 and 2010, taking 1992 as base year.

http://dx.doi.org/10.5772/54549

Impacts	Effects
Global Climate Change – Global warming	Siluriformes–Pimelodidae: long-distance migrations – Alterations in physiological functions to survive in environmental conditions out of an optimal specific interval; – Medium size reduction; – Size of adult stock reduced due to reductions in prey abundance. Characiformes– Short-distance migrations – Alterations in physiological functions to survive in environmental conditions out of an optimal specific interval; – Failure in recruitment due to the mismatch between young fish and food; Perciformes–Cichlidae – Alterations in physiological functions to survive in environmental conditions out of an optimal specific interval; – Failure in recruitment due to impacts on reproductive functions. – Failure in recruitment due to loss of habitat;
– Sea level rise	Siluriformes–Pimelodidae: long-distance migrations – Strong recruitment due to expansion of nursery area at estuary. Characiformes– Short-distance migrations – Reduction of the abundance of less-adapted species for the altered environment; – Changes in the community structure as a response to the alterations in the environment. Perciformes–Cichlidae – Alterations in physiological functions to survive in environmental conditions out of an optimal specific interval; – Failure in recruitment due to impacts on reproductive functions.
Dams	Siluriformes–Pimelodidae: long-distance migrations – Stock abundance reduced due to reductions in the livable area; – Blockage of fish migrations, which create obstacles for freshwater species to complete their life cycles. Characiformes– Short-distance migrations – Change in species abundance because of alterations in the habitat; – Loss of important habitats for young fish (e.g., areas that are seasonally flooded); Perciformes–Cichlidae – Failure in recruitment due to the loss of spawning habitat.

Table 3. The potential impacts of global climate change and dams and their effects on freshwater Amazonian fish

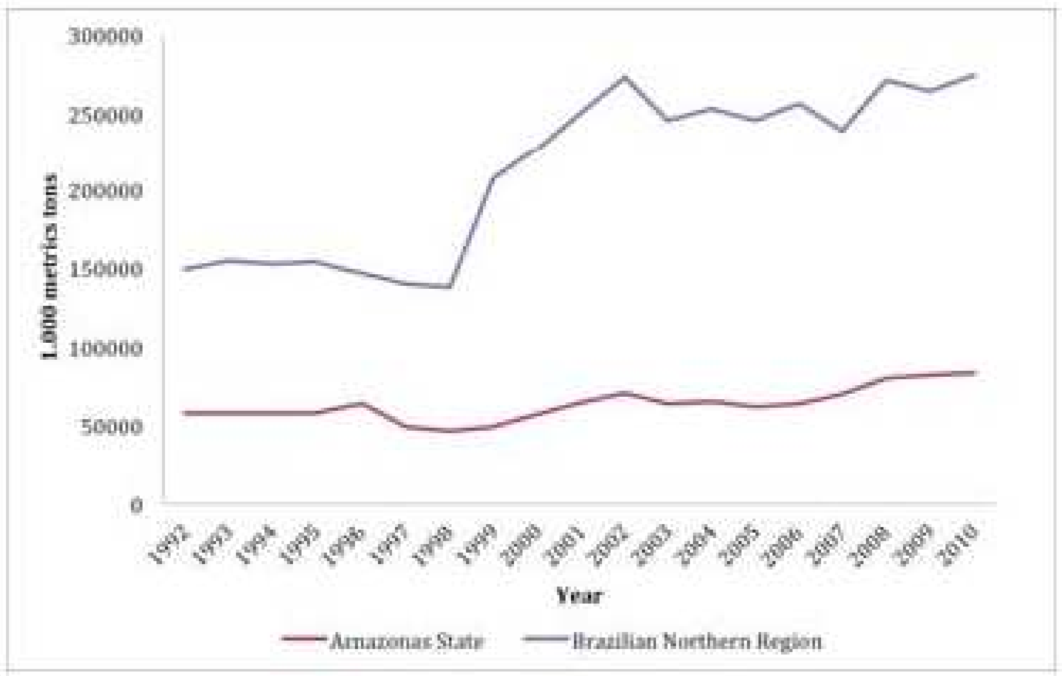


Figure 4. Amazonas State and Brazilian Northern region fisheries production between 1992-2010. (Source: 53, 54).

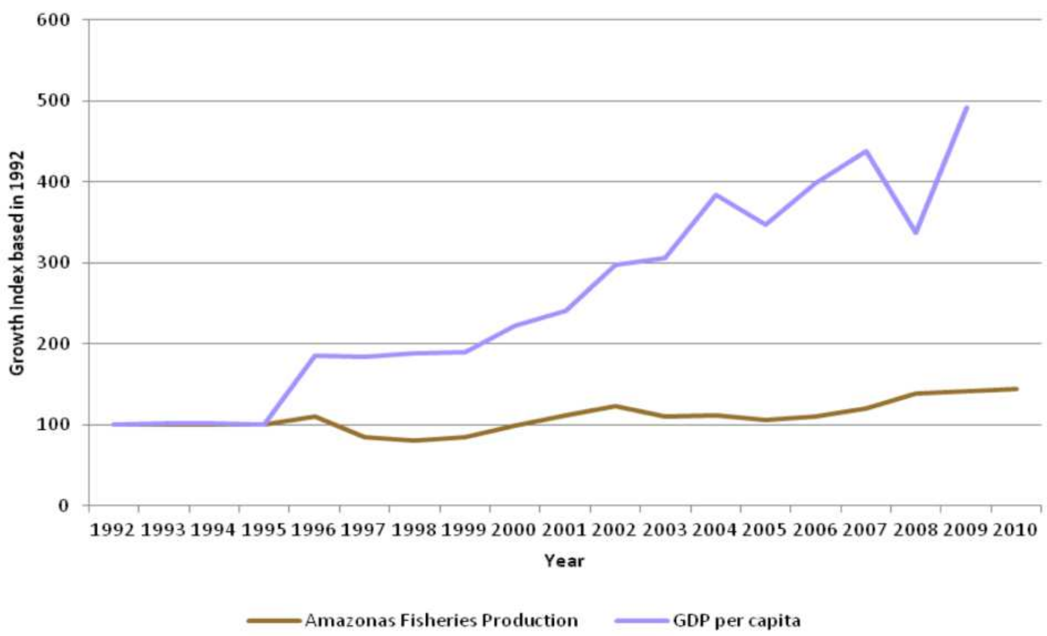


Figure 5. Amazonas State GDP per capita and an index of fish production growth [53, 54].

Taking 1992 as the base year both for a fish production index and GDP, it is possible to see that starting in 1995, GDP per capita grew continuously with fluctuations around the trend due to business cycles. At the same time, the index of fish production also grew but with

http://dx.doi.org/10.5772/54549

much less intensity. It is clear from the graph that while GDP per capita presented a strong growth trend, increments in fish production were very slow.

What relationships do these trends have with global warming? It is clear that fish production does not drive GDP growth, so global climate change is not likely to have much impact on the GDP of Amazonas through the impact of global change on fisheries. This is not to imply that there would not be critically important impacts through other sectors of the economy. Of course, impacts on fisheries would have a large impact on the income of those participating in the commercial fishing industry, and it could have a significant impact on the GDP of small cities in Amazonia (5 to 10 thousand inhabitants) that do not have alternative sources of income. This is particular true for small cities that are sufficiently close to Manaus to sell their catch in this large urban market.

It should be noted that GDP is a measure of market output, not economic benefits and there are a number of ways in which fisheries impact social welfare, both within the urban/industrial area and within the rural communities. For example, the output of subsistence fisheries is explicitly excluded from the measure of GDP because the output is not traded in formal markets. Clearly, small communities will suffer immensely if fisheries are highly impacted by climate change. Moreover, Amazonas has a fish culture, as opposed to the beef culture of the rest of Brazil. As Table I indicates, fish consumption is extraordinarily high, even in urban centers. If fish become scarcer and more expensive, the welfare of the urban centers will be diminished as they are forced to substitute meat and poultry for their traditional fish dishes.

The social welfare impacts of global climate change induced impacts on fisheries are difficult to calculate. The reason for this is that the direct impacts on fisheries may change economic behavior, which could then lead to a series of indirect impacts that could compound the impacts of climate change. These reactions could occur between urban and rural communities, within the fishery sector, or within the subsistence communities.

If the impacts of global climate change on fisheries reduce the quality of life of small communities, it could spur additional migration from the small communities to the urban centers. This would increase the urban externalities associated with population increases as a whole, and those associated with immigration of a group of people without training to participate in the service or industrial sectors of the urban center. Moreover, the introduction of more people with a high preference for fish consumption into the urban center will increase the urban demand for fish, putting more pressure on the fisheries near the urban centers, which are already stressed and showing evidence of decline.

People that remain in small communities will continue to be negatively impacted by the decreased fish populations because of the impacts of global climate change. This could lead to several negative impacts. First, they may react to the change by fishing more intensively to try to compensate for the decline in populations. This will further stress the populations that are already stressed by global climate change. Second, they may switch species, trying to capture species that previously were not high priority, but remain more abundant. In general, these species will be smaller, and the trophic cascading associated with the decline in for-age fish is difficult to predict. Third, they may turn to more hunting to supply their protein needs, leading to other negative impacts on the ecosystem. In particular, the hunting of caiman could lead to impacts on biodiversity as the controlling predators are eliminated from the ecosystem. This would be in addition to the impacts of reductions in intermediate level aquatic predators such as peacock bass (*Cichla* spp.) which would suffer from the negative impacts of global climate change.

Worse impacts could potentially occur if the rural populations increased their participation in other extractive activities, including agriculture, timbering and non-timber forest products. Although the collection of non-timber forest products, such as fruit and fibers is likely to be have a relatively benign direct impact, areas of the forest that were previously not the subject of economic activity could become the subject of economic activity. The heavy presence of people in these previously unharvested areas could lead to impacts on fisheries and wildlife, interfering with the ability of these areas to serve as a reserve for repopulating depleted areas.

Increased participation in timbering and agriculture will lead to deforestation, which has a negative impact on the biodiversity of the forest. Moreover, it will have a negative impact on the aquatic systems. If communities are successful in developing markets for these extractive products, it could lead to a reverse migration of people from urban areas back to the forest, leading to an increasing cycle of degradation.

Both the direct effects of global climate change and the indirect effects associated with the reaction to global climate change will have negative impacts on the social welfare of both urban and rural populations. It is likely that a feedback cycle could develop where the reaction to degradation is more degradation, dramatically reducing both social welfare and ecosystem function.

6. Conclusions

Climate changes and dams are likely to represent the most important threats to freshwater fish around the world. The effects of climate change on the ecosystem will include alterations of the timing, distribution and form of precipitation, as well as the timing of the flood pulse, and the intensity and frequency of floods and droughts. The impacts of these changes on the fish fauna and fisheries are, at that moment, unpredictable at both the species and ecosystem level. Actually, the degree of uncertainty and the low level of knowledge about the biology of the most of Amazonia fish species, make it hard to determine the current impacts of climate changes for each species and for the ecosystem as a whole, and even harder to predict future impacts. In addition to regional impacts, it will be very difficult to predict the impacts of dams for each fish species from the Amazon basin. As we discussed earlier, dams block fish migration, which could be very critical for many freshwater fish species that need to do migrations to complete their life cycles.

One pertinent question is what we can do to minimize the impacts of global climate changes and dams. Actually, we need to identify clearly the possible strategies to avoid human con-

http://dx.doi.org/10.5772/54549

tribution to the magnitude of both sources of impacts. We realize that any intervention on the crescendo of climate change needs action of a very large scale or a very large package of small scale actions. Both of these necessitate development strategies arising from a coordinated source, such as a global agreement. Unhappily, the global negotiations on this issue have made little progress, and we remain distant from an agreement. On the other hand, the effect associated with potential new dams are in the sphere of national decision-making and these impacts could be avoided if the proposed construction does not take place. Thus, it is not too late to find alternatives to Amazonian hydropower for power supply. A global goal to minimize the impacts of both climate change and dams on freshwater fisheries is needed in order to avoid these severe impacts.

Author details

Carlos Edwar de Carvalho Freitas[1,3*], Alexandre A. F. Rivas[1,3], Caroline Pereira Campos[2], Igor Sant'Ana[1], James Randall Kahn[1,3], Maria Angélica de Almeida Correa[1] and Michel Fabiano Catarino[2]

*Address all correspondence to: cefreitas@ufam.edu.br

1 Federal University of Amazonas, Manaus, Amazonas, Brazil

2 National Institute for Amazonian Research, Manaus, Amazonas, Brazil

3 Washington and Lee University, Manaus, Amazonas, Brazil

References

[1] Freitas CEC, Siqueira-Souza FK, Prado KLL, Yamamoto KC, Hurd LE. Fish diversity in Amazonian floodplain lakes. International Journal of Medical and Biological Frontiers 2010;16:128-142.

[2] Honda EMS, Correa CM, Castelo FP, Zapellini EA. Aspectos gerais do pescado no Amazonas. Acta Amazonica 1975;5(1):87-94.

[3] Shrimpton R, Giugliano R. Consumo de alimentos e alguns nutriente em Manaus, Amazonas. Acta Amazonica 1979;9(1):117-141.

[4] Cerdeira RGP, Ruffino ML, Isaac VJ. Consumo de pescado e outros alimentos pela população ribeirinha do Lago Grande de Monte Alegre. Acta Amazonica 1997;27(3): 213-227.

[5] Batista VS, Inhamuns AJ, Freitas CEC, Freire-Brasil D. Characterization of the fishery in river communities in the low-Solimões/high-Amazon region. Fisheries Management and Ecology 1998;5(5):419-435.

[6] Fabré N, Alonso J. Recursos ícticos no Alto Amazonas. Sua importância para as populações ribeirinhas. Boletim do Museu Paraense Emilio Goeldi, Serie Zoologia 1998;14(1):19-55.

[7] Boischio AAP, Henshel D. Fish consumption, fish lore, and mercury pollution - risk contamination for the Madeira River people. Environmental Research 2000;84:108-126.

[8] Murrieta RSS, Dufour DL. Fish and farinha: protein and energy consumption in Amazonia rural communities on Ituqui Island, Brazil. Ecology of Food and Nutrition 2004;43(3):231-255.

[9] Junk WJ, Bayley PB, Sparks RE. The flood pulse concept in river floodplain systems. Special publication of the Canadian Journal of Fisheries and Aquatic Sciences 1989;106:110-127.

[10] Oliver LP et al. Drought sensitivity of the Amazon rainforest. Science 2009;323:1344-1347.

[11] Vieira EF, Isaac VJ, Fabré NN. Biologia reprodutiva do tambaqui, Colossoma macropomum Cuvier, 1818 (Teleostei, Serrasalmidae), no baixo Amazonas. Acta Amazonica 1999;29(4):625-638.

[12] Araujo-Lima CARM, Oliveira EC. Transport of larval fish in the Amazon. Journal of Fish Biology 1998;29:1-11.

[13] Araujo-Lima CARM, Ruffino ML. Migratory Fishes of the Brazilian Amazon. In: Carosfeld J, Harvey B, Ross C, Baer A (eds.) Migratory Fishes of South America: Biology, Fisheries and Conservation Status. Ottawa. The World Bank; 2003. p233-302.

[14] IPCC. Summary for Policymakers. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Solomon S, Qin D, Manning M, Chen Z, Marquis M, Avryt KB, Tignor M, Miller HL (eds.). Cambridge University Press, Cambridge, UK and New York, USA, 2007, 113p.

[15] Shukla J, Nobre CA, Sellers P. Amazon deforestation and climate change. Science 1990;247:1322-1325.

[16] Malhi Y, Roberts T, Betts RA, Killen TJ, Li W, Nobre CA. Climate Change, Deforestation, and the Fate of the Amazon. Science 2008;319:169-172.

[17] Vermeer M, Rahmstorf S. Global sea level linked to global temperature. PNAS 2009; www.pnas.prg/cgi/doi/10.1073/pnas.0907765106 (acessed 5 July 2012).

[18] Becker CD, Genoway RG. Evaluation of the critical thermal maximum for determining thermal tolerance of freshwater fish. Environmental Biology of Fishes 1979;4:245-256.

[19] Ficke AD, Myrick CA, Hansen LJ. Potential impacts of climate changes on freshwater fisheries. Review in Fish Biology and Fisheries 2007;17:581-613.

[20] Lowe-McConnell RH. Ecological Studies in Tropical Fish Communities. Cambridge University Press, Cambridge, England 1987;382pp.

[21] Finer M, Jenkins CN. Amazon and its implications for Andes-Amazon connectivity. PLoS ONE 2012;7(4): e35126. doi:10.1371/journal.pone.0035126.

[22] Marengo JA, Nobre CA, Tomasella J, Oyama MD, Oliveira GS, Oliveira R, Camargo H, Alves LM, Brown IF. The drought of Amazonia in 2005. Journal of Climatology 2008;21:495-516.

[23] Humphries P, Baldwin DS. Drought and aquatic systems: an introduction. Freshwater Biology 2003;48:1141-1146.

[24] Matthews WJ, Marsh-Matthews E. Effects of drought on fish across axes of space, time and ecological complexity. Freshwater Biology 2003;48:1232-1253.

[25] Agostinho AA, Pelicice FM, Gomes LC. Dams and the fish fauna of the Neotropical region: impacts and management related to diversity and fisheries. Brazilian Journal of Biology 2008;68(4,suppl.):1119-1132.

[26] Agostinho AA, Gomes LC, Veríssimo S, Okada EK. Flood regime, dam regulation and fish in the Upper Paraná River: effects on assemblages attributes, reproduction and recruitment. Reviews in Fish Biology and Fisheries 2004;14(1):11-19.

[27] Barthem RB, Goulding M. The catfish connection: ecology, migration, and conservation of Amazon predators. Biology and Resource Management in the Tropics Series. Columbia Press, New York 1997;144 p.

[28] Agudelo E, Salinas Y, Sánches CL, Muñoz-Sosa DL, Alonso JC, Arteaga ME, Rodrígues OJ, Anzola NR, Acosta LE, Núñez M, Valdés H. Bagres da la Amazonia Colombiana: Uno recurso sin fronteras. Fabré NN, Donato JC, Alonso JC (Eds). Instituto Amazónico de Investigaciones Científicas SINCHI. Programa de Ecosistemas Acuáticos. Editorial Scripto, Bogotá 2000;252p.

[29] Barthem RB, Ribeiro MCLB, Petrere M. Life strategies of some long-distance migratory catfish in relation to hydroelectric dams in the Amazon Basin. Biological Conservation, 1991;55:339–345.

[30] Ruffino ML, Isaac VJ. Dinamica populacional do Surubim-Tigre, Pseudoplatystoma tigrinum (Valenciennes, 1840) no médio Amazonas (Siluriformes, Pimelodidae). Acta Amazonica 1999;29(3):463-476.

[31] Pérez A, Fabré NN. Seasonal growth and life history of the catfish Calophysus macropterus (Lichtenstein, 1819) (Siluriformes: Pimelodidae) from the Amazon floodplain. Journal of Applied Ichthyology 2009;25:343–349.

[32] Loubens G, Panfili J. Biologie de Colossoma macropomum (Teleostei: Serrasalmidae) dans le bassin du Mamoré (Amazonie bolivienne). Ichthyological Exploration of Freshwaters 1997;8:1–22.

[33] Ribeiro MCLB, Petrere Jr. M. Fisheries ecology and management of the Jaraqui (Semaprochilodus taeniurus, S. insignis) in Central Amazonia. Regulated Rivers: Research and Management 1990;5:195–215.

[34] Fernandes CC. Lateral migrations of fishes in Amazon floodplain. Ecology of Freshwater Fish 1997;6:36-44.

[35] Mota SQ, Ruffino ML. Biologia e pesca do curimatá (Prochilodus nigricans Agassiz, 1829) (Prochilodontidae) no Médio Amazonas. Revista UNIMAR 1997;19:493-508.

[36] Ruffino ML, Isaac VJ. Life cycle and biological parameters of several Brazilian Amazon fish species. The ICLARM Quaterly 1995;18:41-45.

[37] Jepsen DB, Winemiller KO, Taphorn DC. Age structure and growth of peacock cichlids from rivers and reservoirs of Venezuela. Journal of Fish Biology 1999;55:433-450.

[38] Xenopoulos MA, Lodge DM, Alcamo J, Märker M, Shulze K, Van Vuuren DP. Scenarios of freshwater fish extinctions from climate change and water withdrawl. Global Change Biology 2005;11:1557-1564.

[39] Marshall BG, Forsberg BR, Hess LL, Freitas CEC. Water temperature differences in interfluvial palm swamp habitats of Paracheirodon axelroldi and P. simulans (Osteichthyes: Characidae) in the middle Rio Negro, Brazil 2011;22(4):377-383.

[40] Almeida-Val V, Val AL, Duncan WP, Souza FCA, Paula-Silva MN, Land S. Scaling effects on hypoxia tolerance in the Amazon fish Astronotus ocellatus (Perciformes: Cichlidae): contribution of tissue enzyme levels. Comparative Biochemistry and Physiology;125B:219-226.

[41] Cushing DH. Climate and fisheries. Academic Press, London 1982;373p.

[42] Cushing DH. Plankton production and year-class strength in fish populations: an update of the match/mismatch hypothesis. Advances in Marine Biology 1990;26:249-293.

[43] Bailly D, Agostinho AA, Suzuki HI. Influence of the flood regime on the reproduction of fish species with different reproductive strategies in the Cuiabá River, Upper Pantanal, Brazil. River Research and Applications 2008;24:1218-1229.

[44] Koehn JD, Hobday AJ, Pratchett MS, Gillanders BM. Climate change and Australian marine and freshwater environments, fishes and fisheries: synthesis and options for adaptation. Marine An Freshwater Research 2011;62:1148-1164.

[45] Agostinho AA, Vazzoler AEAM, Gomes LC, Okada EK Estratificacíon especial y comportamiento de Prochilodus scrofa en distintas fases del ciclo de vida, en la planicie de inundacíon del alto río Paraná y embalse de Itaipu, Paraná, Brazil. Revue due Hydrobiologie Tropicale 1993;26:79-90.

[46] Barrela W, Petrere Jr M. Fish community alterations due to pollution and damming in Tietê and Paranapanema Rivers (Brazil). River Research and Applications 2003;19:59-76.

[47] Porto L, McLaughlin R, Noakes D. Low-head barrier dams restrict the movements of fishes in two lake Ontario streams. North American Journal of Fisheries and Management 1999;4:1028-1036.

[48] Gomes LC, Agostinho AA. Influence of the flooding regime on the nutritional state and juvenile recruitment of the curimba, Prochilodus scrofa, Steindachner, in Upper Paraná river, Brazil. Fisheries Management and Ecology 1997;4:263-274.

[49] Angermeier PL. Ecological attributes of extinction-prone species: loss of freshwater fishes of Virginia. Conservation Biology 1995;9:143-158.

[50] Food and Agriculture Organization. The State of World Fisheries and Aquaculture 2010. Rome 2011.

[51] Sumaila UR, Cheung WWL, Lam VWY, Pauly D, Herrick S. Climate change impacts on the biophysics and economics of world fisheries. Nature Climate Change 2011; doi: 10.1038/NCLIMATE1301.

[52] Merino G, Barange M, Blanchard JL, Harle J, Holmes R, Allen I, Allison EH, Badjeck MC, Dulvy NK, Holt J, Jennings S, Mullon C, Rodwell LD. Can marine fisheries and aquaculture meet fish demand from a growing human population in a changing climate? Global Environment Change 2012;22:795-806. Doi: 10.1016/j.gloenvcha.2012.03.003.

[53] Food and Agriculture Organization. Statistical databases. Available in: <http://www.fao.org>. Acessed on September 2012.

[54] Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis – IBAMA. Estatística da Pesca 2007. Brasil – Grandes Regiões e Unidades da Federação 2007.

[55] Ministério da Pesca e Aquicultura. Produção Pesqueira e Aquícola – Estatística 2008 e 2009 – 2010.