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A REVIEW OF MAJOR RIVER BASINS AND LARGE LAKES RELEVANT TO INLAND FISHERIES

Cover photograph © FAO/Simon Funge-Smith: Fishing gears on the Tonle Sap, Cambodia, one of the most productive inland fisheries in the world.

A REVIEW OF MAJOR RIVER BASINS AND LARGE LAKES RELEVANT TO INLAND FISHERIES

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PREPARATION OF THIS DOCUMENT

This review was developed to provide a comprehensive summary of the inland fisheries of the major river basins of the world. The review was undertaken by the Hull International Fisheries Institute, University of Hull, UK, in cooperation with the Fisheries Resources Branch (FIAF) of the FAO Fisheries and Aquaculture Division. The review was edited by Robin Leslie. The purpose of producing this review was twofold, firstly to attempt to compile information on fish catches at a basin level rather than national level and secondly to complement the national information contained in the FAO Fishery and Aquaculture Circular, *Review of the state of world fishery resources: inland fisheries* (FAO Fisheries and Aquaculture Circular No. C942 Rev.3). The presentation of inland fishery information at the basins' level also provides, perhaps for the first time, a picture of the large transboundary river basins and their fishery contributions to food and biodiversity. It is hoped that this basins' perspective will also encourage greater appreciation of the role of inland fisheries in broader basin-level water management and development dialogues.

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ABSTRACT

This review presents summary information on 45 river and great lake basins of the world, which support inland fisheries. The information presented is drawn from published information in peer-reviewed journals as well as grey literature. Each basin summary is presented in a common format, covering the description of the fishery, estimates of catch and numbers of people engaged in the fishery, important biodiversity features and threats to the fishery. An analysis of the replacement costs of inland fish of the basin is also presented. This is expressed in terms of the water, land and greenhouse gas footprint that would arise if the inland fish that are currently produced had to be replaced with other forms of food (such as aquaculture fish, livestock or field crops).

CONTENTS

ACRONYMS AND ABBREVIATIONS

BMU	Beach Management Unit
CAMPFIRE	Communal Area Management Project For Indigenous Resources (Zimbabwe)
CFRI	Central Fisheries Research Institute
CIC	Intergovernmental Coordinating Committee (La Plata Basin)
CITES	Convention on International Trade in Endangered Species
CORA	Chippewa Ottawa Resource Authority
CPUE	Catch per unit effort
DoF	Department of Fisheries (Kenya)
EIA	Environmental Impact Assessment
ESIA	Environmental and Social Impact Assessment
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FDC	Fisheries Development Centre (Plurinational State of Bolivia)
FRD	Food Resources Department (Botswana)
GAFRD	General Authority for Fish Resources Development
GLIFWC	Great Lakes Indian Fish and Wildlife Commission
ICAR–CIFRI	Indian Council of Agricultural Research, Central Inland Fisheries Research Institute
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
JRC	Joint Rivers Commission (India)
KWS	Kenya Wildlife Services
LIFDC	Low Income Food Deficit Country
LMB	Lower Mekong Basin
LMR	Lower Mississippi River
LNDA	Lake Nasser Development Authority
LVFO	Lake Victoria Fisheries Organisation
MMR	Middle Mississippi River
MPA	Ministry of Fisheries and Aquaculture (Brazil)
MRC	Mekong River Commission
NBI	Nile Basin Initiative
nei	Not elsewhere identified
OKACOM	Okavango River Basin Water Commission
OMVS	Organization pour la Mise en Valeur du fleuve Sénégal
PRC	People’s Republic of China

SADC	Southern African Development Community
SEPEC	Colombian Fisheries Statistical Service
SIS	Small Indigenous Species
SVP	Shared Vision Programme
TAC	Total Allowable Catch
UMR	Upper Mississippi River
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
USAID	United States Agency for International Development
USSR	Union of Soviet Socialist Republics
WHO	World Health Organization
WWF	World Wildlife Fund
YRRC	Yellow River Conservancy Commission
ZAMCOM	Zambezi River Commission

INTRODUCTION

'Inland waters' are defined by the Food and Agriculture Organization of the United Nations (FAO) as "lakes, rivers, streams, canals, reservoirs and other landlocked waters" (FAO, 2018). Globally, inland waters cover a total area of about 7.8 million km^2 (De Graaf *et al.,* 2015) and represent about 0.01 percent of the volume of water on Earth (Stiassny, 1996). About 40 percent of all fish species and 20 percent of all vertebrate species inhabit inland waters (Helfman *et al.,* 2009). However, 65 percent of inland water resources are classed as either moderately or highly threatened by anthropogenic stressors (Vörösmarty *et al.,* 2010).

Once described as a backward, informal and marginal economic activity (Platteau, 1989), inland fisheries have a vast social and economic value for millions of people globally (Béné *et al.,* 2015a). Inland capture fisheries are crucial to improving food security and nutrition, diversifying livelihoods, providing income and healthy aquatic ecosystems, and can directly contribute towards the UN Sustainable Development Goals (SDGs). Almost 95 percent of the world's inland fisheries is caught and consumed in developing countries (Bartley *et al.,* 2015; FAO and WorldFish Centre, 2008), and Low Income Food Deficit Countries (LIFDCs) accounted for 43 percent of the inland fish catch in 2015 (Funge-Smith, 2018).

Distribution of inland fish catch is worldwide, but the major inland fisheries tend to be concentrated in the tropical and subtropical latitudes and from developing countries, except for the Russian Federation and Finland (Table 1).

Global inland fishery production increased between 2 percent and 3 percent annually to 11.9 million tonnes in 2017 (FAO FishStatJ, 2019). This growth mainly occurred in Asia and Africa, which accounted for 67 percent and 25 percent of the reported inland fishery catch, respectively. Fish catches from the Americas, Europe and Oceania are considerably lower than those from Asia and Africa, accounting for a combined 8.5 percent of the total inland fisheries catch. Reported inland production from the Americas,

Table 1. Top 30 inland fish-producing countries in 2017

Country	Catch (tonnes)	% GC	Country	Catch (tonnes)	% GC
China (People's Republic of)	2 186 330	18.3	Mexico	168 072	1.4
India	1 593 100	13.4	Philippines	162 543	1.4
Bangladesh	1 163 608	9.8	Viet Nam	158 878	1.3
Myanmar	887 320	7.4	Pakistan	139 215	1.2
Cambodia	528 493	4.4	Chad	107 045	0.9
Indonesia	467 531	3.9	Mali	106 221	0.9
Nigeria	420 078	3.5	Kenya	98 579	0.8
Uganda	389 629	3.3	Iran (Islamic Republic of)	97 419	0.8
United Republic of Tanzania	331 175	2.8	Mozambique	97 021	0.8
Russian Federation	275 310	2.3	Ghana	90 000	0.8
Egypt	261 195	2.2	Zambia	84 000	0.7
Democratic Republic of the Congo	230 000	1.9	Sri Lanka	81 870	0.7
Brazil	224 910	1.9	Lao People's Democratic Republic	70 900	0.6
Malawi	199 455	1.7	Ethiopia	56 001	0.5
Thailand	190 510	1.6	Congo	38 842	0.3
Total	**9 348 644**	**78.3**		**1 556 606**	**13.0**

Note: GC = total global inland fishery catch = 11 927 911 tonnes in 2017.

Source: FAO FishStat J (2019)

Europe and Oceania has stabilized and has not shown any significant increase in decades, primarily due to the dominance of recreational fishing in these areas. Thirty countries, almost exclusively in Africa and Asia, produced 91 percent of the global inland fisheries catch in 2017 (Table 1). Ten of these countries accounted for 69 percent and a further ten countries an additional 15 percent.

USING A BASIN APPROACH FOR ASSESSING INLAND FISHERIES

The global inland fishery statistics compiled by FAO are reported at national rather than river basin level. The national figure is thus an aggregated amount compiled from a range of data from fisheries based on different aquatic habitats (wetlands, lakes, reservoirs and rivers, and possibly estuaries). The national figure therefore represents the catches of various basins and fisheries. Very few of the large river basins are wholly contained within a single country boundary and are typically part of a larger transboundary river or watershed. This means that the state of a particular river basin fishery typically requires the compilation of subnational data from a number of countries.

FAO and others have commented on the spatial and temporal fragmentation of knowledge and research on inland fisheries and their associated aquatic ecosystems (Coates, 2002; Allan *et al.,* 2005; FAO, 2010; World Bank, FAO and WorldFish Centre, 2010; Funge-Smith, 2018). The lack of more accurate information and limited downscaled trend information gives rise to a range of opinions and perspectives on the state of inland fisheries. These range between a view that the decline of inland fisheries is inevitable in the face of population growth, overfishing and the multiple pressures and threats to inland water systems (Friend, Arthur and Keskinen, 2009), to a more positive outlook that hidden inland fisheries are more productive and resilient than previously thought (Bartley *et al.,* 2015).

The answer lies somewhere in between, as there are strong differences in the resilience, biodiversity and pressures on inland fisheries among regions and latitudes. Inland fisheries are threatened by multiple anthropogenic stressors, such as habitat modification, climate change and water pollution, which may be locally severe or have larger transboundary implications. Not all inland fisheries are in decline; it is therefore possible that while a country may report increasing or stable inland fish production, this is potentially masking a decline in one or more river basin fisheries. Conversely, enhancement or management measures may be increasing fishery production in reservoirs and man-made waterbodies, contributing to increased national inland fish catches. Nutrient inputs to waterbodies can drive their productivity and increase their yield (e.g. Lake Victoria, small tropical floodplain waterbodies).

If a basin is wholly contained within a country (or a country wholly contained with a basin) then this may be representative of the status of a country's inland fishery. More typically, a basin is shared by a number of countries and the status of an inland fishery within a basin will be a reflection of the impacts of several countries' activities, typically in an upstream–downstream continuum. This also means that the threats to the fishery and its management may require both national and collective action and may have transboundary implications.

The aim of this review is to provide an overview of the major river and lake basins of the world that support significant inland fisheries and to provide an indication of their current status, especially where they transcend national boundaries.

RIVER BASIN DATA COLLECTION METHODOLOGY

To determine the contribution of river basins to global fish production and to support the assessment of the overall state of inland fisheries, the 45 most important river basins (Table 2) based on the perceived importance of their fisheries from a commercial (small-scale), subsistence or recreational perspective, or as a combination of all three, were chosen. This priority list of basins covered an estimated 88 percent of global inland capture fishery production, based on the FAO national statistics of the countries associated with these basins. In addition to the river basins and waterbodies selected, a country example (Finland) was also selected as this provided a regional balance and its national production, although not associated with a single river basin, was sufficient to warrant inclusion.

Table 2. River basins covered in this review, by subregion

Region	Subregion	River basins	
Africa	Great Lakes	Lake Victoria* Lake Malawi	Lake Tanganyika* Lake Turkana
	Southern	Zambezi River Lake Kariba	Limpopo River Okavango River
	Nile River Basin	Nile River*	
	West coastal	Niger River*	Volta River
	Sahel	Lake Chad* Senegal River	Gambia River
	Congo Basin	Congo River*	
Americas	South	Amazon River* Tocantins–Araguaia River Magdalena River	Orinoco River La Plata River Lake Titicaca
	North	Mississippi–Missouri River Yukon River	Great Lakes Basin
Asia	South	Indus River* Brahmaputra River	Ganges River
	Southeast	Mekong River* Red River* Tonlé Sap Lake*	Irrawaddy River* Salween River* Mahakam River
	Central	Caspian Sea*	Ural River
	China	Yangtze River* Pearl River*	Yellow River Amur River
Europe	East	Danube River	
	North (country profile)	Finland	
Oceania	Oceania	Murray–Darling	Sepik River
Russian Federation	Russian Federation	Volga River	Ob–Irtysh River

*Denotes a major inland basin with fish catch ≥100 000 tonnes.

Basin profiles

A standardized approach to each basin profile is used that covers the following elements:

Profile section	Contents
Basin overview	Fish diversity Fish introductions
Basin fishery overview	Fishing methods Fish trade Employment Estimated basin fish production (composite figure aggregating sub-basin waterbodies) Status of the fisheries: catch trends Aquaculture in the basin Recreational fisheries
Equivalent food to replace fisheries production (for appropriate basins)	Energy replacement Water demand Land requirement Greenhouse gas emissions
Fisheries management	
References	

Search engines, such as Google Scholar, Web of Science and ProQuest, were used to find the most recent estimates of inland fishery catches for the chosen rivers and lakes from peer review and grey literature sources and official national data. Literature and report information on fish diversity, employment, aquaculture production and development, fisheries management and fisheries and waterbody characteristics for each river basin was collected and presented as basin profiles (see standardized approach above). The references and information therein were used to snowball the information sources and obtain the most comprehensive data review possible regarding the status of fisheries in each river basin. Google Translate was also used to search specific countries for catch information.

Basin catch estimates

Data collected from the literature were for the most recent year available. For some basins (particularly in Africa), fisheries data dated back to the 1960s and 1970s. It is unlikely that the fish catch for the rivers concerned would have remained static over that period of time, given increased exploitation in most fisheries across the world coupled with population growth, therefore, some of the fisheries data should be treated with caution. This issue highlights the lack of consistent fisheries assessment outputs available within many river basins over the years – a fundamental problem with inland capture fisheries statistics (Funge-Smith, 2018). It is important to note that the quality of information will be different in different areas, and interpretation of data for one fishery may not be applicable to another. For example, although catch information collected for each basin was the best available data, for some basins, this may refer to fish production for individual tributaries that make up a basin, while for others it represents catch by country within a basin or catch by fishery sector (e.g. commercial/recreational)

Where possible, the catch estimate for each basin was compiled from the subsidiary parts of the basin and its associated waterbodies (Table 3) according to available information. This catch information was often spread over a considerable period of time and thus is indicative of catches, but cannot be considered either a maximum catch (as fish catches may have developed further) or representative of current levels of catch (in cases where the fishery has declined).

Where a national fishery catch exceeded the aggregate of basin estimates for that country, the difference was attributed to the rest of the country lying outside of the basins, where inland fisheries were likely to occur (excluding arid or desert areas). This was the case for the Republic of India, the People’s Republic of China and Brazil only. Inland fish catches for large lakes and reservoirs, were included in the basins where those waterbodies occurred unless otherwise stated (e.g. Lake Tanganyika, Lak Malawi). In some cases, available data did not disaggregate by individual river basins, in which case this data is presented for all of the rivers concerned (e.g. some rivers in the Russian Federation).

For mainland China, inland fishery statistics are reported by province, therefore the fish catch from one province could reflect the fish catch from more than one river basin. In order to allocate fish catch to river basins, the area that each river basin in China occupied in a province was established using Arc GIS and the proportion of the provincial fish catch (based on 2015 fisheries data from Zhao and Shen, 2016) was allocated pro rata to the area of each river. Although this involved the major assumption that fish catches are spread evenly across a province and therefore can only be indicative of a basin’s fish production, without subprovince-level production statistics, this was deemed the only available method for allocation.

Table 3. Inland fishery catches attributed to hydrobasins: 14 643 634 (96 percent of total inland fishery 15 226 991 tonnes catch accounted)

Basin	Catch (tonnes)	% of global catch	Ref	Basin	Catch (tonnes)	% of global catch	Ref
Mekong (incl. Tonlé Sap)	2 328 000	15.29	1	Amur	75 304	0.49	1
Nile (incl. Lake Victoria)	1 487 787	9.77	1	Sabarmati	70 191	0.46	
Ayeyarwady	1 198 917	7.87	1	Volga	68 200	0.45	1
Yangtze	1 047 827	6.88	1	Lena, Indigirka, Alazeya, Olenek, Popigay, Yana	67 078	0.44	3
Brahmaputra River and floodplain	846 258	5.56	1	Sri Lanka (all basins)	66 910	0.44	
Amazon	653 678	4.29	1	La Plata Basin (including Paraná River)	63 849	0.42	1
Ganges River	537 904	3.53	1	India south coast (Kerala, Tamil Nadu)	62 913	0.41	5
Xun Jiang (Pearl)	502 084	3.30	1	Java - Timor	58 942	0.39	4
China coastal drainages	421 159	2.77		South peninsular Thailand (sub-basins)	52 659	0.35	
Hong (Red River)	377 543	2.48	1	Cauvery	45 061	0.30	5
Chao Phraya	364 216	2.39	2	Kolyma	39 678	0.26	3
Niger	326 000	2.14	1	Angola coastal drainages	38 514	0.25	2
Yasai (India)	251 376	1.65	5	India west coast (Kerala, Maharashtra, Karnataka)	35 519	0.23	5
Indus	239 503	1.57	1	Finland (all basins)	34 585	0.23	1
Sumatra	217 808	1.43	4	Brahamani	33 590	0.22	5
Philippine Archipelago	203 366	1.34	2	Japan (all basins)	32 868	0.22	2
Salween	194 886	1.28	1	Limpopo	31 010	0.20	1
Krishna	187 960	1.23	5	Senegal	30 540	0.20	1
Godavari	184 145	1.21	5	Madagascar	25 940	0.17	2
Lake Tanganyika	166 609	1.09	1	Danube	24 786	0.16	1
Mexican basins	151 416	0.99	2	Ob-Irtysh	22 694	0.15	1, 3
Lake Chad basin	147 500	0.97	1	Laurentian Great Lakes	20 596	0.14	1
Congo (excl. Lake Tanganyika)	144 743	0.95	1	Sulawesi	19 365	0.13	4
Pennar	144 709	0.95		Kamchatka peninsular	17 614	0.12	3
Lake Malawi and Shire sub-basin	141 643	0.93	1	Tocantins	16 360	0.11	1
Caspian Sea	116 557	0.77	1	Neva	16 255	0.11	3
Huang He (Yellow)	109 149	0.72	1	Mahakam River	15 525	0.10	1
Ziya He	109 149	0.72		Kalimantan	15 125	0.10	4
India east coast drainages	103 985	0.68	5	India NE coast drainages	14 807	0.10	5
Orinoco	91 024	0.60	1	Korean peninsular (all basins)	14 333	0.09	2
Zambezi (excl. Lake Malawi/Shire sub-basins)	87 890	0.58	1	Ural	13 630	0.09	1
Mahanadi	79 782	0.52	5	Narmada	13 611	0.09	5
Volta	76 391	0.50	1	Dnieper	12 600	0.08	3
Gambia river	76 000	0.50	1	Tapti	11 676	0.08	5

Table 3. (cont.) Inland fishery catches attributed to hydrobasins: 14 643 634 (96 percent of total inland fishery 15 226 991 tonnes catch accounted)

Basin	Catch (tonnes)	% of global catch	Ref	Basin	Catch (tonnes)	% of global catch	Ref
Anadyr	10 669	0.07	3	Sepik	4 000	0.03	1
Sweden	10 520	0.07	2	Murray - Darling	3 432	0.02	1
Yenisei, Pyasina, Taz, Pur, Khatanga	9 036	0.06	1,3	Ogooué river (Gabon)	2 507	0.02	2
Don	9 000	0.06	3	Fly	2 350	0.02	2
Mississippi - Missouri	8 988	0.06	1	NE South America, S. Atlantic Coast	1 350	0.01	2
Mahi	7 058	0.05	5	Okavango River	1 000	0.01	1
Ouémé river	6 484	0.04	2	New Zealand	832	0.01	2
Peninsula Malaysia	5 924	0.04	2	England and Wales	747	0.005	2
Magdalena	5 808	0.04	1	Pacific and Arctic Coast drainages (Yukon)	509	0.003	2
Mezen	4 860	0.03	3	Iceland	201	0.001	2
Northern Dvina	4 860	0.03	3	Shebelli - Juba	100	0.001	2
Pechora	4 860	0.03	3	Ireland	78	0.001	2
Kuban	4 000	0.03	3				

Sources: 1) Case studies covered in this review; 2) Funge-Smith (2018); 3) Calculated from FAO (2020) *The inland fisheries of the Russian Federation: their current status for food provision and employment (in press)*; 4) Calculated from *BPS-Statistics Indonesia* (2018); 5) Calculated from India Department of Animal Husbandry, Dairying and Fisheries (2014)

Statistics for freshwater fisheries in India were obtained for each state (Government of India, 2014). A similar allocation approach was used as for China. Freshwater fish catch was assigned by the area of each basin in a particular state using Arc GIS and the state-level fisheries statistics. However, in this case, the state-level statistics were presented as a combination of both inland aquaculture and capture fisheries production. The partitioning of the fish production into capture and aquaculture was reconciled by examining the species composition of inland production for 2012 in the FAO FishStatJ (2018) statistics and the statistics presented by the Government of India (2014). The following methods were used:

1. The aquaculture production of species groups was removed from the combined production presented in the Indian State Statistics:
    - Indian major and minor carp species and Pangasius catfish (= freshwater siluroids) were subtracted from the combined production for 'major carp', 'minor carp' and 'wallago/Pangasius' species.
    - Snakeheads were subtracted from 'snakeheads' (= murrels) combined production.
    - Grass carp were subtracted from the combined production of 'exotic carp'.
    - Anadromous and brackishwater species reported for inland waters (kelee shad, giant tiger prawn) were subtracted from the combined production of 'other diadromous species'.
    - Freshwater prawn, climbing perch, river prawn, river fish (not elsewhere indicated) and trout were subtracted from 'other freshwater fish'.
2. The residual catch was attributed to capture fishery production and allocated to each state on a pro rata basis according the overall production of each of the groups for that state:
    - This approach assumed that there was a constant ratio between cultured and captured fish in each state.
3. The allocated state capture fishery catches were then allocated to each fishery basin according to the area of that basin with the state:
    - This assumed that fish catches were distributed evenly across a basin from the headwaters to its delta.
4. Where a basin was transboundary, the relevant production statistics from the other countries were included:
    - For example, for the Brahmaputra River Basin, which mostly flows through India but has a large floodplain in Bangladesh, fishery statistics for the floodplain fishery in Bangladesh were also included in the fishery total for this basin.

Statistics for freshwater fisheries of the Russian Federation were obtained from the FAO review 'The inland fisheries of the Russian Federation: their current status for food provision and employment' (in preparation) based on delineated fishing regions for data collection. Basin delineation was not exact, as more than one basin may occur within a region and thus freshwater catch was broken down into their corresponding basins. It was possible to assign some data directly to named basins and their associated reservoirs. For example, official freshwater fish catches for the Volga River and Caspian Sea are reported together in the statistics but are separated out into their individual basins for this report.

Country catch estimates

Inland fish catches also occur outside major river basins (Table 4). There are situations where a country that reports inland fish catch is wholly located within a hydrobasin[1] that is not associated with a major river. Countries that have inland fisheries but lie outside of the major river basins were treated in one of three ways:

- **Large archipelagic countries (Indonesia and the Philippines):** These countries have many small basins, but few large river basins. They still have considerable inland fish catches from other freshwater resources (lakes, swamps, small rivers) spread across multiple islands. In this case, inland fish catch at the subnational level was used for assignment to the respective islands. Where the catch could be clearly attributed to a large river basin (e.g. the Mahakham River in Kalimantan), this was subtracted from the total for that island and the river basin was mapped (Mahakham basin 21, p. 143).
- **An entire country is contained within its own hydrobasin:** For example: island states such as Fiji, Iceland, Japan, Madagascar, New Zealand, Sri Lanka and the United Kingdom; countries that have considerable freshwater resources (e.g. lakes) that are not associated with large rivers (e.g. Iceland, Norway and Sweden).
- **A country contains one or more hydrobasins, but other areas that are arid.** Inland fish catch was attributed to those "productive" basin, or sub-basin areas, that lie within a country's borders (e.g. Chad, Mexico).
- **National catches that could not be attributed to a particular hydrobasin or sub-hydrobasin**: These were assigned to the rest of the country concerned.

[1] Note that major hydrobasins are not synonymous with river basins, they represent water catchment and drainage areas. Thus, a major hydrobasin may not be associated with any major rivers (e.g. many coastal hydrobasins and most islands).

Table 4. Countries with inland fishery catch outside listed river basins: 583 357 tonnes (3.8 percent of the global inland fishery catch)

Countries with inland fishery catches outside major basins	Catch (tonnes)	% of global catch	Countries with inland fishery catches outside major basins	Catch (tonnes)	% of global catch
Bangladesh (outside Brahmaputra)	177 733	1.17	Dominican Republic	1 234	0.01
Mozambique (excl. Zambezi, Lake Nyasa)	67 305	0.44	Tunisia	1 192	0.01
Kazakhstan	41 489	0.27	France	1 187	0.01
Turkey	34 176	0.22	Tajikistan	1 176	0.01
Uzbekistan	22 954	0.15	Afghanistan	1 000	0.01
Iraq	22 848	0.15	Costa Rica	1 000	0.01
Nepal	21 500	0.14	Greece	940	0.01
Germany	21 349	0.14	Belarus	869	0.01
Benin (Coastal lagoons lakes)	20 770	0.14	Jamaica	698	0.005
Peru (excl. Lake Titicaca)	20 494	0.13	Montenegro	662	0.004
Poland	18 376	0.12	Nicaragua	606	0.004
Morocco	15 006	0.10	Haiti	600	0.004
Turkmenistan	15 000	0.10	Azerbaijan	568	0.004
Gabon	8 500	0.06	El Salvador	458	0.003
Armenia	8 140	0.05	Norway	408	0.003
Ukraine (excl. Dnieper, Danube)	7 028	0.05	Austria	350	0.002
Papua New Guinea (excl. Fly & Sepik)	6,350	0.04	North Macedonia	350	0.002
Spain	6,000	0.04	Bosnia and Herzegovina	300	0.002
Bolivia (excl. Lake Titicaca)	5 000	0.03	Belgium	283	0.002
Czechia	3 841	0.03	Latvia	226	0.001
Italy	3 800	0.02	Denmark	174	0.001
Estonia	2 654	0.02	Guinea Bissau	150	0.001
Fiji	2 600	0.02	Slovenia	141	0.001
Guatemala	2 360	0.02	Ecuador	105	0.001
Liberia	2 200	0.01	Eswatini	65	0.000
Sierra Leone	2 100	0.01	Kyrgyzstan	63	0.000
Switzerland	2 043	0.01	Lesotho	52	0.000
Slovakia	1 971	0.01	Republic of Moldova	50	0.000
Netherlands	1 904	0.01	Cyprus	20	0.000
Albania	1 482	0.01	Georgia	20	0.000
Lithuania	1 437	0.01			

Source: FAO FishstatJ, 2019.

Large lakes

Inland fish catches from large lakes with a surface area exceeding 400 km^2 are presented as reported for the lake as a whole (Table 5). These values are not included in the catch of the respective basins in which they lie as shown in Table 4. In the basin profiles given in this review, the lake catches are included in their respective basin with the exception of: the Caspian Sea, the Laurentian Great Lakes, Lake Tanganyika (separated out of the Congo Basin) and Lake Malawi (separated out of the Zambezi Basin) which have their own dedicated profile. Lake Chad and its associated floodplains are treated as a hydrobasin and not included in the lake catches presented here.

Table 5. Large lakes (>400 km^2) that support inland fisheries: 2 069 545 tonnes (13.6 percent of global inland fishery catch)

Countries/basins containing major lakes	Major lakes (>400 km^2) that support inland fisheries	Catch (tonnes)	% of global catch
Nile Basin	Lake Victoria	1 061 107	6.97
Cambodia	Tonlé Sap	246 000	1.62
Tanganyika Basin	Lake Tanganyika	166 609	1.09
Zambezi Basin	Lake Malawi/Nyasa	141 643	0.93
Caspian Sea	Caspian Sea	116 557	0.77
Uganda/Democratic Republic of the Congo	Lake Albert	110 000	0.72
Uganda	Lake Kyoga	34 700	0.23
Philippines	Laguna de Bay	20 400	0.13
Zambia	Lake Bangwelu	17 849	0.12
Democratic Republic of the Congo/Rwanda	Lake Kivu	17 714	0.12
Turkey	Lake Van	12 744	0.08
Laurentian Great Lakes	Lake Erie	12 473	0.08
Philippines	Lake Taal (Batangas)	11 800	0.08
Philippines	Lake Buluan	11 200	0.07
Bolivia Plurinational State of/Peru	Lake Titicaca	10 160	0.07
Philippines	Lake Lanao (Mindanao)	10 000	0.07
Thailand	Songkhla Lake (Thailand)	9 634	0.06
Canada	Lake Winnipeg	6 428	0.04
Uganda/Democratic Republic of the Congo	Lake Edward	6 000	0.04
Zambia/Democratic Republic of the Congo	Lake Mweru	5 953	0.04
Philippines	Other Philippine lakes	5828	0.04
Philippines	Naujan (Philippines)	5 000	0.03
Kenya/Ethiopia	Lake Turkana	4 413	0.03
Russian Federation	Lake Ladoga	2 900	0.02
Laurentian Great Lakes	Lake Michigan	2 833	0.02
Namibia	Lake Liambezi	2 700	0.02
Laurentian Great Lakes	Lake Huron	2 685	0.02
Laurentian Great Lakes	Lake Superior	2 418	0.02
Estonia/Russian Federation	Lake Peipus/Pepsi	2 388	0.02
Russian Federation	Lake Baikal	1 900	0.01
Russian Federation	Lake Onega	1 893	0.01
Democratic Republic of the Congo	Lake Tumba	1 500	0.01

Countries/basins containing major lakes	Major lakes (>400 km^2) that support inland fisheries	Catch (tonnes)	% of global catch
Indonesia	Lake Toba	1 150	0.01
Armenia	Lake Sevan	1 000	0.01
Canada	Great Slave lake	1 000	0.01
Mongolia	Lake Khövsgöl	325	0.002
Ethiopia	Lake Tana	292	0.002
Laurentian Great Lakes	Lake Ontario	187	0.001
Canada	Lake Nipigon	152	0.001

Source: Case studies in this review.

SUMMARY OF RESULTS

Distribution of inland catches

The world's inland capture fisheries are concentrated in tropical and subtropical latitudes, with a few notable exceptions (e.g. Northern Russian Federation/Siberia, North American Great Lakes, Finland, Paraguay/Plata River in South America) (Figure 1, Table 6). The breakdown of estimated fish catches summed from Table 3 to Table 5 indicates the largest inland fish catch of 5.05 million tonnes from Asia, 3.17 million tonnes from south Asia, 2.91 million tonnes from Africa, 2.31 million tonnes from China and east Asia, 1.02 million tonnes from South and central America, 0.58 million tonnes from the Russia Federation and central and western Asia, 140 885 tonnes from Europe, 30 093 tonnes from North America and 19 564 tonnes from Oceania.

The country distribution of inland fisheries catches is determined by the presence of major inland aquatic ecosystems, such as lakes, rivers and floodplains that support productive habitats (Funge-Smith, 2018). In addition, catch distribution is also high where population densities of rural people able to exploit these resources are higher, or where the local climate or economy hinder the cultivation of crops or livestock, and where there is a strong tradition of fish consumption (Funge-Smith, 2018). The most prominent inland capture fisheries are associated with freshwater systems that are generally biodiversity hotspots, but all, virtually without exception, are threatened by intense exploitation and human development activities that are degrading habitats and exploiting water resources to the detriment of the fisheries (Welcomme *et al.,* 2010). All the fisheries are also likely to be impacted by climate change (Harrod *et al.,* 2018). These issues are discussed in more detail for the individual basins in this report.

Table 6: Total inland fishery catch and percentage of global catch by major regions

Region	Catch (tonnes)	Percentage of global total
Southeast Asia	5 052 276	33.2
South Asia	3 171 360	20.8
Africa	2 907 998	19.1
China and east Asia	2 311 873	15.2
South and central America	1 016 040	6.7
Russian Federation and central Asia	576 902	3.8
Europe	140 885	1.0
North America	30 093	0.2
Oceania	19 564	0.13
Total	**15 226 991**	

Not all the major inland fisheries are covered in this review, but that does not imply that the fish catches from these rivers are any less crucial or unimportant. Unfortunately, fisheries information for these waterbodies, and many other smaller waterbodies, was not adequate, or not available in sufficient detail, to warrant individual river basin assessments. In addition, fisheries surveys have not been carried out on some rivers, or the only catch data available were considerably dated, raising concerns about their reliability in relation to their current contribution to overall catches.

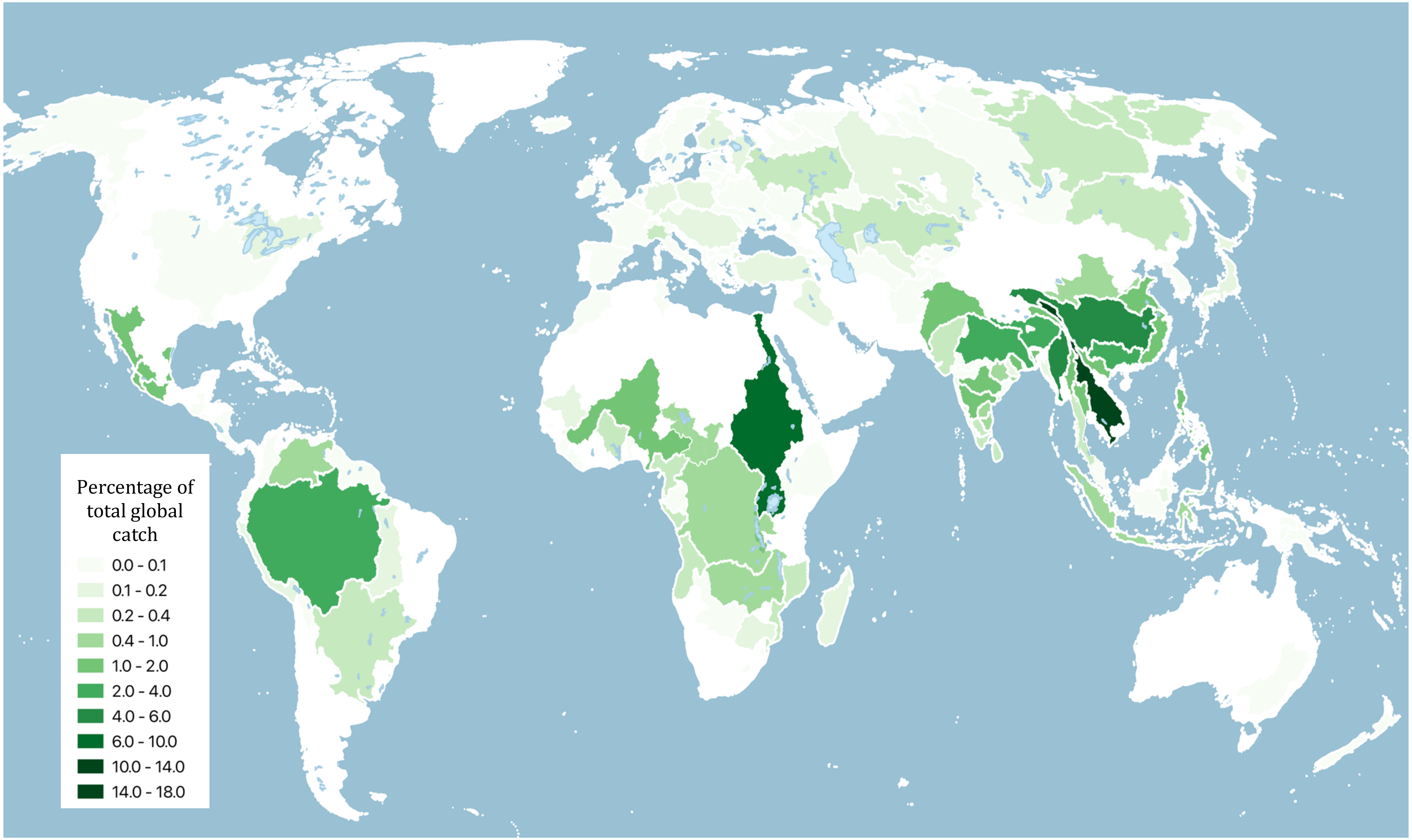

Figure 1. Concentration of inland fish catch by major basins and countries, expressed as percentage of total global catch in 2015. Map conforms to UN Map of the World No. 4170 Rev. 19, October 2020.

Equivalent food replacement of inland fisheries

From an ecosystem perspective, using 'river basins' as units is the ideal for reporting on the status and health of inland fisheries. This is due to the physical and ecological interrelationships between fisheries within basins and the basin-level impacts of water and land management on fisheries production.

Inland fisheries are impacted by both internal (fishing pressure and management interventions) and external factors (e.g. agriculture, hydropower, pollution and climate change) (Welcomme *et al.,* 2010). The scale of impact on inland fisheries depends on the intensity of the activity and the current state of the environment.

Inland fisheries are important for local or regional food and nutritional security (Lynch *et al.,* 2016) and it is informative to understand how their decline or loss will affect dependent rural communities directly and indirectly. This covers both the impact on food security, primary protein and nutrition supply and demand, as well as the environmental impacts of alternative food production systems that would be required to replace the loss of any inland fishery production.

The use of monetary value, where the loss of fish might be easily distinguished as loss of export value, loss of fishing days and an increase in food prices, may be applicable for distinct commercial fisheries, but this is restricted to a few large commercial inland fisheries that can employ it. An alternative approach is the use of environmental implications of replacing fisheries, which is perhaps better suited to quantify the loss of inland fisheries that are poorly defined and can provide decision-makers with a picture of the burdens incurred by fish loss that are easy to understand. The approach is based on the quantification of the effect by which the loss of fisheries would require replacement of fish with alternative forms of food (fish directly from aquaculture, or terrestrial forms such as livestock or plant-based sources). All of these cultivated replacements would require an expansion of land or water under cultivation, an increase in water use and potentially an increase in carbon emissions. The question also arises about whether a particular basin or region has the available agricultural land and water resources to allow such an expansion of production.

To understand this, estimates for replacement of fish by alternative foods were carried out using various replacement foods that are produced within the specific basin countries, and represent an upscaling of existing food production of these items. Estimates for inland fish replacement were modelled on either a 50 percent or 100 percent loss to reported fishery production from the river basin. Differences were distinguished between the apparent threats facing a river system; where there were notable threats to the fishery of a basin, or where fisheries production was known to have declined, replacement estimates were based on a 50 percent loss to fishery production, as an indication of a more realistic scenario of fish loss. Where there were few perceived threats to a river basin or a lack of information regarding the state of fisheries, replacement estimates were modelled on 100 percent loss of fisheries catch. Although it is extremely unlikely that the whole of a river basin fishery would be lost, this represents a 'worst case scenario' indicating the maximum impact of replacing fish with alternative foods. Alternatively, a 100 percent loss scenario indicates the amount of water, land and carbon emissions that is currently being spared, or not used by having access to inland fisheries.

Details regarding the methodology are outlined in Ainsworth (2020) and Ainsworth and Cowx (2018). The estimated percentage proportional use of water resources required for fish replacement were basedon national Agricultural water use. These estimates were extracted from AQUASTAT (FAO, 2016) and represent the most recent year for which agricultural water use estimates were available. This data is correct as of January 2018 and agricultural water use data may not fully reflect the current agricultural water use within each country or any adjustments made afterwards. The online AQUASTAT core database is referenced as FAO (2016).

Similarly, pastoral, arable and agricultural land areas used to derive percentage proportional land area for fish replacement was derived from FAOSTAT for the year 2016, for all countries. This data is correct as of June 2018 and does not account for any adjustments made afterwards, therefore, the percentage proportional land area may not fully reflect the current agricultural land area available in each country.

Replacement estimates were not modelled for rivers where the main function of the fisheries was for recreation or small-scale commercial operation, i.e. these fisheries were not essential in providing food and maintaining food security within the basin itself. The aim of this section is to determine the potential food replacement equivalents in terms of alternative food production (equivalent kilojoules from fish), land and water use and carbon footprint if inland fisheries are compromised by human development. The replacement estimates should be treated as approximations, as they are based on estimated fisheries productions values, most of which are considered underestimations.

CONCLUSIONS

Catch and country distribution of inland fisheries is worldwide. The largest inland fisheries are in Southeast Asia, the People's Republic of China (PRC) and the African Great Lakes, with four basins within these regions having an estimated fisheries production exceeding 1 million tonnes (the Mekong River, Yangtze River, Irrawaddy River and Lake Victoria). Fishery production from the 45 river basins considered in this review constituted 88 percent of the FAO-estimated inland fisheries production in 2017 (11.9 million tonnes). Combined with the additional basins, hydrobasins and country production outside of major basins highlighted in Tables 3 to 5, indicate that estimated inland fisheries production could be 15.2 million tonnes. Although this estimate is higher than the FAO estimate, it is believed that the readjusted estimate may still be an underestimation of actual fish production. Subsistence fishing is rarely reported in fish statistics and there is a lack of freshwater fisheries studies and monitoring in each region and illegal or unreported fishing continues to be a problem.

Replacement of capture fisheries by basin, as outlined in the profiles, indicates that for some areas the water demand and land requirements to replace fisheries will not be feasible. For example, replacement of fisheries from Lake Victoria will require substantial increases in alternative food production. This is a particular concern in a region where increasing prevalence of drought and changing environmental conditions have increased the occurrence of crop and livestock failures; an increase in water demand for food production may not be feasible and ultimately may lead to human food and water scarcity. The loss of inland fisheries will be just as detrimental to the environment as for the millions who depend on the sector. Acknowledging the cost implications to food security and food supply of replacing inland capture fisheries will be important for recognizing the global importance of this diverse sector.

This review is intended to serve as a basis for further downscaling of analysis of river basin and subnational inland fisheries catches. There are discrepancies between the total inland fishery catch figures presented in this review and the global total catch figures compiled by FAO. This reflects that not all the basin data were drawn for the same year and the compiling of fish catches from basins and waterbodies may not reflect the national inland catch overall totals reported to FAO. To the greatest extent possible, care has been taken to ensure that there has been no double counting among basins and countries. In most cases, it is assumed that the higher total figures are a result of the inclusion of inland catches that are generally not covered by routine national reporting, typically subsistence or recreational production.

It is hoped that this review will provide a better understanding of the importance of some river basins for inland fisheries. Crucially, the basin profiles provide an analysis of the threats and current catch trends in each basin, which are imperative in our future understanding and knowledge of potential issues that may impede inland fisheries production. As not all the inland fishery hydrobasins that are identified in Table 3 are covered in this review, it is also hoped that they may be covered in subsequent updates.

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1 NIGER RIVER

1.1 OVERVIEW

The Niger is the third longest river in Africa (4 200 km) with the fourth largest catchment area on the continent; it is the ninth largest river system in the world. The river is separated into four sections: the Upper Delta, the Inner Delta, the Middle Niger and the Lower Niger. The source of the river is in the Fouta Djallon Massif in Guinea. The Inner Delta covers up to 30 000 km^2 during the wet season and is fed by many tributaries, channels and swamps. The river loses about 65 percent of its flow in the Inner Delta due to seepage and evaporation. In the Middle Niger, the river receives water from five tributaries from Burkina Faso – the Gouroual, Dargol, Sirba, Gouroubi and Tapoa. In the Lower Delta, there is a major confluence with the Benué River, resulting in a 450 percent increase in the river's flow. The river is dammed in this region at Kainji and Jebba (AU-IBAR, 2015). The climate of the basin is variable: the Upper Delta and Lower Delta climate is tropical, while the Inner Delta overlays the transition between the humid Guinea climate and dry Sahel climate (Brown, 2015; Brown and Mockrin, 2015).

Table 1-1. Characteristics of the Niger River

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
Nigeria	571 869	26.763	81 747 182	143
Mali	555 723	26.007	13 520 271	24
Niger	491 635	23.008	15 479 870	31
Algeria	161 056	7.537	106 958	1
Guinea	95 780	4.482	3 226 366	34
Cameroon	86 803	4.062	4 859 708	56
Burkina Faso	83 412	3.904	3 353 979	40
Benin	44 723	2.093	1 740 599	39
Côte d'Ivoire	23 572	1.103	581 308	25
Chad	19 476	0.911	1 331 466	68
Mauritania	2 727	0.128	86 720	32
Sierra Leone	17	0.01	397	23
Total	**2 136 795**	**100**	**126 034 823**	**43**

Fish diversity

Fish diversity from the Niger and Benué Rivers is outlined in Table 1-2. The most abundant families in the Niger Basin are Cyprinidae (37 species), Mormyridae (31 species) and Mochokidae (30 species). In the Benué River there are 182 species, with a species composition similar to that of the Niger River, but endemism is lower with only two species (*Garra allostoma* and *Chiloglanis niger*) (FishBase, 2017). Quensiere (1994) grouped fishes of the Niger River Basin into two major categories based on various behavioural and physiological adaptations: (i) migratory species that exploit environmental variability and have high fecundity and a short breeding period and (ii) opportunistic species that are less mobile and have physiological adaptations to help them survive anoxic conditions on the floodplains (AU-IBAR, 2015).

Table 1-2. Fish diversity of the Niger and Benué rivers

River	Total diversity	Endemic species	Introduced species
Niger River	260	21	0
Benué River	182	2	0

Source: FishBase (2017).

1.2 FISHERIES OVERVIEW

Fishing in the Niger River is mainly concentrated around the large floodplains of the Inner Delta or in the Sélingué, Kainji, Jebba and Lagdo reservoirs (Ogilvie *et al.,* 2010). Fishing activities can be classified into three categories: (i) artisanal fish harvesters who use rudimentary gear and only fish in ponds and channels. They are the most abundant fishers for which fishing is for subsistence and is conducted in conjunction with farming; (ii) sedentary fishers who live in permanent villages or camps and practise traditional fishing during the falling water or low water season using standard gear such as gillnets or seine nets; (iii) full time or migrant fishers who fish throughout the year and use more modern specialized gear (AU-IBAR, 2015). In the Central Delta, 76 species were recorded in fish landings (Laë, 1995), of which 17 species accounted for 85 percent of the total catch. Cichlids dominated catches (26.6 percent), the main species being *Oreochromis niloticus* (10.20 percent), *Tilapia zillii* (8.3 percent) and *Sarotherodon galileus* (6.2 percent). In Nigeria the demersal target species exploited by artisanal fishers are croakers (*Pseudotolithus*), threadfins (*Galeoides, Pentanemus, Polydactylus*) and sole (*Cynoglossus*) (Laë *et al.,* 2004).

Fishing methods

Fishing methods vary according to the type of fisher, hydrological season and fish abundance. Variations in water level prevent fishers using the same gear throughout the year and seasonal fishing techniques are essential to maintain sufficient yield. The fishing gear of the Niger River can be grouped into six major categories: hunting gear (harpoons), push nets, seine nets (consisting of small or large, purse or seine nets), gillnets (mono- or multifilament nets, fixed nets or drift nets), traps and lines (baited lines and unbaited hook lines) (Laë *et al.,* 2004). In the Central Delta fixed and drift nets (which account for 40 percent of the catch) are the most successful gear, followed by small traps (15.7 percent of the catch), cast nets (14.9 percent) and multiple-hook lines (10.6 percent) (Laë *et al.,* 2004).

Fish trade

Fish and fishery products from the Niger River are worth an estimated USD 100 million (based on production of 240 000 tonnes per year) (Neiland and Béné, 2008). Due to the lack of infrastructure and lack of means to conserve fresh fish, approximately three-quarters of domestic production is marketed in processed form after smoking, drying and frying (FAO 2007).

Employment

Table 1-3 indicates participation in Niger River Basin fisheries. In Guinea, fishery statistics are rare, but the number of professional and part-time fishers was estimated at around 6 000. In Mali, as the population of the delta has increased so has the fishing population; on Lake Selingue, the number of fishing units is about 800 (Laë and Weigel, 1995). In Niger, fishing is mainly a full-time occupation; in the 1960s there were approximately 1 500 active fishers (Bacalbasa-Dobrovici, 1971), increasing to 2 600 in 1980 (Price, 1991), but from 1983 to 1985 fishing effort declined by 50 percent due to the Sahelian drought and high fishing pressure (Malvestuto and Meredith, 1989). In the Lower Niger system, the number of fishers was estimated at 10 000 on the Niger River, 6 300 on Lake Kainji, 3 900 on Lagdo Reservoir and 5 140 on the Benué River (Welcomme, 1985). The population of fishers decreased between 1990 and the 2000s because of the lack of government input subsidies to purchase fishing equipment (Laë *et al.,* 2004). The total number of fishers in the Niger Delta increased from 466 602 in 1991 to 1 177 308 fishers in 2000 (Laë *et al.,* 2004). Given that much of the data in Table 1-3 are outdated, we can expect that participation in fishery-based activities has increased.

Table 1-3. Participation in Niger River Basin fisheries activities

Country/area	Fishers (year)	Year	Reference
Guinea	6 000		Laë *et al.* (2004)
Mali	62 000	1987	Morand *et al.* (1990)
Niger	2 600	1980	Price (1991)
Lower Niger	25 340		Welcomme (1985)
Nigeria/Niger Delta	1 177 308[1]	2000	FDFS (2000)
Total	**1 273 248**		

[1]Fishers consist of 666 320 full-time fishers, 486 566 part-time fishers and 24 422 occasional fishers (FDFS, 2000).

Estimated fisheries production

Table 1-4 indicates the estimated fisheries production for the Niger River by country (Laë *et al.,* 2004). Problems linked to fisheries surveys and inconsistencies in data between countries impacted the accuracy of data collected. There is a general lack of effort from the riparian states to carry out robust fishery assessment and even where statistics are available, data are difficult to interpret. Some countries only report adult fishers (males ≥ 12 years old), while other countries base their catch on the number of fishing licences or number of fishing households, and there may be double counting of migrant fishers who move from area to area; as a result, there are likely to be inconsistencies in the fisheries data that follow.

Total annual fish catches from the Niger River and its tributaries are estimated at 300 000 tonnes (Laë *et al.,* 2004). The Benué River has an estimated catch of around 10 000 tonnes per year (Nieland and Béné, 2008). Historical data are rare, but it is possible to track the main changes since the 1940s, when fishing was free and profitable and fish were abundant. Fishing pressure and fishing population have increased and the intensification of fishing has resulted from the introduction of synthetic nets.

The estimates in Table 1-4 are likely an underestimation of the actual fishery yield from the river as the data have been recycled by various sources for a lengthy time (Laë *et al.,* 2004; Morand *et al.,* 2009; AU-IBAR, 2015). Additionally, much of the fishery data available date from 1950 to the 1990s and are therefore unlikely to be representative of current catch trends. Also, Morand *et al.* (2009) identified possible sources of error with fisheries data from the Niger Basin countries.

Table 1-4. Estimated fisheries production for the Niger River

Country	Catch estimate (tonnes)	Year	Reference
Guinea	6 000	n/a	Laë *et al.* (2004)
Niger	16 000		
Mali	133 000		
Nigeria	171 000		
Total:	**326 000**		

Status of the fisheries: catch trends

Estimates from FAO/UN (1971) suggested that Niger River fisheries catches were in the region of 120 000 tonnes in the 1960s and ranged between 80 000 and 200 000 tonnes between the 1950s and 1970s.

The Middle and Upper Niger River were modified between 1950 and 1990 by two consecutive droughts, building of two dams and rapid intensification of fishing pressure. The droughts that occurred in 1973 and 1984 were responsible for a decrease in river flow and the size of the floodplain was reduced from 20 000 km^2 to 5 000 km^2.As a result of the droughts and loss of floodplain inundation, catches from the Niger River declined from 209 000 tonnes in 1973 to 167 000 tonnes in 1991 (Laë, 1992). In Mali, the impact of the Sahelian drought led to a 50 percent decrease in fisheries production in the Central Delta compared to predrought levels (Neiland and Béné, 2008). Fish catch composition has also changed with an increasing prevalence of small species in the catch and elimination of large species (Laë *et al.,* 2004).

However, since 1995 the total fish landings began to increase because of better floods in the Central Delta (Laë *et al.,* 2004). In Niger, annual fish landings in the 1960s were about 4 000 to 5 000 tonnes with a reported catch per fisher of 2.7 tonnes to 3.3 tonnes (Bacalbasa-Dobrovici 1971). Before the drought years, total catches were close to 7 000 tonnes (Talatou, 1995) and then dropped to around 900 tonnes in 1983 (Malvestuto and Meredith, 1989) because of the severe Sahelian drought. Since the end of the drought the annual fish catch fluctuated between 2 000 and 4 000 tonnes before increasing to over 10 000 tonnes in the 1990s. In Mali, fish yields showed a rising trend from 40 kg/ha to 120 kg/ha from 1968 to 1990 from a shift to smaller younger fish (Laë, 1995).

Aquaculture

Aquaculture is not a traditional practice in West Africa and despite efforts to improve its development, aquaculture statistics in West Africa are usually not accurate due to lack of financial resources and monitoring. Recent development of the aquaculture subsector has not been homogenous and only a few countries have had any success in producing farmed fish. Nigeria is the largest aquaculture producer in sub-Saharan Africa and around 20 species are farmed, with particular emphasis on tilapia, catfish and cyprinids (Laë *et al.,* 2004).

Recreational fishing

Annual fishing festivals on large bodies of water are popular activities, particularly in Nigeria, where the Argungu Fishing Festival has become an international tourist attraction (FAO, 2007). However, the state and scale of recreational fishing and the types of fishes caught are not known.

1.3 THREATS TO THE FISHERIES

Climate change

Climate change models indicate that there has been warming in West Africa, but there are variations in the range of warming from 2 °C to 6 °C by 2100 across models (Christensen *et al.,* 2007). Climate models, however, are not consistent with predictions for future precipitations levels. Some models predict an increase in rainfall and others a decrease (Vigaud *et al.,* 2011; Berg *et al.,* 2013), but these changes will be important (ranging from -20 percent to +20 percent in annual rainfall) (Sultan *et al.,* 2013). Changes to rainfall levels could result in the delayed onset or offset and shortening of the wet season (Biasutti and Sobel, 2009). Changes in rainfall levels and occurrences of drought conditions have led to strong fluctuations in river discharge with a generally negative trend from 1960 to 2010 (Descroix *et al.,* 2013). In West Africa there has been little research on the potential impacts of climate change on fish stocks (Katikiro and Macusi, 2012). However, fishery catches in the Niger River have a strong positive relation with river flow. Severe drought conditions in the 1970s and 1980s caused a 50 percent decline in fisheries production (from 100 000 tonnes to 50 000 tonnes) of the Inner Niger Delta resulting in the loss of about USD 20 million per year (Neiland and Béné, 2008). Climate variability over the coming decades could cause further disruptions to fishery production in the Niger River.

Fishing pressure and overfishing

Fishing pressure has increased rapidly within the basin due to a growing population (which has doubled every 20 years) and the introduction of synthetic nets, which have increased fishing efficiency. The catch composition from the Niger River has changed with a substantial increase in smaller, highly productive fishes replacing large fish species. High fishing effort has led to the increased dominance of young fish; in 1950 the average age at capture of *Alestes dentex* and *A. baremoze* was over two years (Daget, 1956) and that of *Tilapia zillii* was almost three years. In 1990, most species were caught in their first year of life (Laë, 1992), including *Labeo senegalensis, Brycinus leuciscus, Sarotherodon galilaeus* and *Tilapia zillii* – over 78 percent of the catch being in its first year (Laë *et al.,* 2004). Mesh sizes decreased from 50 mm in 1975 to 24 mm to 33 mm after 1983 (Laë *et al.,* 2004), a further sign of overfishing.

Habitat modification

Four dams have been built along the Niger River and its tributaries, which have led to the creation of the large Selengue, Markala, Kainji and Lagdo reservoirs. These cover over 1 400 km^2 and have had an impact on fish population dynamics and abundance downstream of the dams. For instance, in Mali, the Markala and Selengue dams have contributed to an increase in the impact of drought conditions, through a reduction in the already reduced water flows: the annual fish loss to total fish catch was estimated at around 5 000 tonnes (Laë, 1992). In Nigeria, changes in fish fauna following the construction of the Kainji Dam led to a 50 percent reduction in fish catches between Jebba and Lokoja from 1967 to 1969 (Otobo, 1978). There was also a change in species composition from Characidae, Mormyridae and Clariidae to predatory species such as *Lates niloticus* and Bagridae (Sagua, 1978).

1.4 EQUIVALENT FOOD REPLACEMENT

Pro-poor policies have not, to date, considered the fisheries sector, due to its perceived unimportance. The importance of fish to food security within the Niger Basin has not yet been realized, yet its fisheries are of major importance to food security, job creation and livelihood stability. Guinea, Mali, Niger and Nigeria are classed as Low Income Food Deficit Countries (LIFDCs) by FAO and fish make a large contribution to the diet, particularly in Guinea and Nigeria, where fish represent 32.5 percent and 43.1 percent of total animal proteins (FAO, 2011). Due to the fisheries declines already experienced as a result of drought and overfishing, equivalent replacement estimates were established for a 50 percent loss to the total fishery production (Table 1-4) and the replacement discussion will be based on the countries from Table 1-4 (Guinea, Mali, Niger and Nigeria). Replacement food sources consist of aquaculture (tilapia), livestock (beef, pork and chicken) and crops (cassava and maize).

Table 1-5. Food production (tonnes), water (km^3), land (km^2) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km^3 (percentage of agricultural water use)	Land required to replace fisheries in km^2 (percentage of inland water area/ pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Tilapia	93 476 (305.0)	0.3 (2.4)	4 248 (0.3)	0.02
Beef	98 098 (14.5)	1.5 (13.1)	11 319 (1.1)	6.14
Pork	51 304 (19.1)	0.3 (2.7)	6 996 (0.7)	0.03
Chicken	161 574 (43.9)	0.7 (6.1)	4 335 (0.4)	0.38
Maize	207 604 (1.6)	0.3 (2.2)	370 (0.06)	0.008
Cassava	117 229 (0.2)	0.2 (1.9)	104 (0.02)	

Energy replacement: Table 1-5

Aquaculture is not well developed in West Africa, and as such, to replace kilojoules from capture fisheries tilapia would require the equivalent of 305 percent of current production (production in 2015 was 30 644 tonnes). Over 92 percent of current tilapia production for the Niger Basin comes from Nigeria (28 284 tonnes in 2015), therefore, to meet demand in the other riparian countries, tilapia aquaculture would have to increase substantially. Chicken production would require the largest increase from a terrestrial animal resource, equivalent to 44.0 percent of current production (2014 production was 367 535 tonnes).

Water demand: Table 1-5

Replacement of capture fisheries with beef would result in the largest increase in water demand, which is equivalent to 13.1 percent of agricultural water use from the riparian countries (agricultural water use was 11.5 km^3 in 2016). Chicken production would require the next largest increase in water use, equivalent to 6.1 percent of agricultural water withdrawals. The remaining replacement foods would require similar amounts of water to replace capture fisheries, which would be equivalent to 1.9 percent to 2.7 percent of agricultural water use.

Land requirement: Table 1-5

Beef production would require the largest land conversion, equivalent to 1.1 percent of pastureland from the riparian countries (pastureland area in 2014 was 1.1 million km^2). Farmed tilapia production would require land conversion, equivalent to 0.3 percent of the Niger Basin area in Guinea, Mali, Niger and Nigeria (Table 1). Chicken production would require the smallest land conversion, equivalent to 0.03 percent of the pastureland from the riparian countries.

Greenhouse gas emissions: Table 1-5

Carbon emissions from 50 percent loss to the Niger River fishery were estimated at 594 080 tonnes. Replacement of capture fisheries would result in a net increase in carbon emissions, the highest of which would be for beef production (6.14 million tonnes), followed by chicken production (0.38 million tonnes), pork production (0.03 million tonnes) farmed tilapia production (0.02 million tonnes) and maize (8 261 tonnes).

1.5 FISHERIES MANAGEMENT

National management strategies

In Mali, until the beginning of the 1990s, the government was the owner of all waterbodies and tried to implement a centralized management model. This was based on issuing of fishing licences to allow fishing access, enforcement of national regulations to prevent overfishing and assistance in data and technical information collection. However, one of the weaknesses of this system was that these regulations were uniformly applied to the whole country and prevented adaptation of management to the environment or fishing practices (Laë *et al.,* 2004). A decentralization process began in 1995 which led to the creation of fisheries councils which were obliged to deal with all important fisheries issues, including fish farming, fishery agreements and management of fisheries within agricultural and hydroelectric development (FAO, 2007).

In Niger, fishing is managed through Legislation Law No. 98-042, 1998 on fisheries. This law defines modes of access to the fishery, protection measures, closed areas and gear prohibitions. The rural fishing sector is also governed by its own set of legislative text and regulations known as the Rural Code, which aims to protect rural operators and support the conservation and management of natural resources (FAO, 2005).

In Nigeria, inland fisheries are governed by the Inland Fisheries Decree No. 108, 1992, which sets regulations regarding mesh sizes, prohibition of poisoning and control of construction of barriers and diversions. However, this law has been considered ineffective due to lack of resources to administer control. The Code of Conduct for Responsible Fisheries, prepared and adopted by FAO, is being used as the strategy for fisheries management nationally and regionally. It is hoped that this will lead to rehabilitation of aquatic resources, particularly fish resources in the Niger River (Laë *et al.,* 2004).

Transboundary management

The Niger Basin Authority was created in 1987 to promote cooperation amongst member states and ensure the integrated development of the Niger River Basin resources (including fishing and fisheries). Some of the main objectives of the Niger Basin Authority are:

- Coordinate national water management policies to ensure equitable sharing of water resources;
- Formulate an agreement for the general policy for the development of the basin;

- Design and conduct studies, research and surveys and carry out monitoring; and
- Create an integrated development plan for the basin (AU-IBAR 2015).

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2 VOLTA RIVER

2.1 OVERVIEW

The Volta River Basin is the ninth largest basin in sub-Saharan Africa and drains 70 percent of Ghana. The Volta River is fed by three major tributaries: the Black Volta, sourced in Burkina Faso, which drains an area of 147 000 km², the White Volta, which drains 10 000 km² including much of central Ghana and the Oti River which drains 72 000 km² of northwest Benin and Togo. The three tributaries join in northern Ghana to form the Volta River (van Zweiten *et al.,* 2011). The Oti River provides 30 percent to 40 percent of the Volta's annual flow (Béné, 2007). In 1964, the Volta River was dammed at Akosombo creating Lake Volta, the largest artificial lake in Africa with a surface area of 8 300 km² (Biney, 1990). Other major waterbodies in the Volta Basin include the Bagré and Kompienga reservoirs (Burkina Faso). The Volta Basin has four climatic zones, from lowland rain forest in the south, to the Sahel–Sudan climate in the north where the average rainfall is below 1 000 mm (van Zweiten *et al.,* 2011).

Table 2-1. Characteristics of the Volta River

Country	Area of the river basin (km²)	Percent area of the river in countries	Population of the river basin	Population density/km²
Burkina Faso	172 073	42	13 916,645	81
Ghana	167 176	41	9 484 404	57
Togo	26 930	7	2 306 954	86
Mali	16 830	4	743 681	44
Benin	15 132	4	795 871	53
Côte d'Ivoire	12 971	3	361 954	28
Total	**411 111**	**100**	**27 609 509**	**58**

Fish diversity

There is little information regarding the fish fauna of the Volta River prior to its damming (van Zweiten *et al.,* 2011). As a result, there are varying estimates for the number of fish species. Brown and Thieme (2015) estimated that there are 145 fish species in the Volta River and that many species adapted to riverine habitats have declined or been lost from the system because of damming. Alternative estimates from Roberts (1967) recorded 112 fish species during the pre-impoundment stage and Denyoh (1969) recorded 108 species during the filling stage; van Zweiten *et al.* (2011) suggested 74 species in the Volta River of which about 60 are commercially important.

Fish introductions

There is no information regarding any fish species introduction into the Volta River. Vanderpuye (1984) suggested that as native fish species filled all the niches in the ecosystem it had not been necessary to introduce any exotic species.

2.2 FISHERIES OVERVIEW

Fisheries are of huge socio-economic importance in Ghana as fish and fish products contribute nearly 70 percent of the country's animal protein requirements. More than 90 percent of the inland fish production in Ghana is produced from Lake Volta (Béné, 2007). The fishery is solely artisanal, with about 17 500 canoes actively fishing the lake. Based on surveys it is estimated that about one-third of the catch is consumed locally, while 50 percent of the remaining two-thirds passes through the main markets (Béné, 2007). By contrast, fishing in Burkina Faso is a secondary activity after farming and is only conducted by 25 percent of the population on a seasonal basis. In Burkina Faso, there is also no real fishing tradition, possibly due to a lack of a stable high concentration of the resource. Fisheries instead form one component of an integrated multiactivity-based livelihood strategy (Béné, 2007).

Fishing activities are conducted on the main river channel, seasonal ponds and Lake Volta itself. Annual production of fishes is linked to the floodplain and the size and composition of the fish community is heavily dependent on annual fluctuations in water levels (van Zweiten *et al.,* 2011). There are around 60 commercially important species within the basin and commercial catches are dominated by tilapiine species. The composition of the commercial catch from 1991 to 1998 comprised *Chrysichthys* spp. (34.4 percent), tilapias (28.1 percent), *Synodontis* spp. (11.4 percent), *Labeo* (3.4 percent), mormyrids (2.0 percent), *Heterotis* spp. (1.5 percent), *Clarias* spp. (1.5 percent), schilbeids (1.4 percent), *Odaxothrissa mento* (1.4 percent), *Bragrus* spp. (1.3 percent) and *Citharinus* spp. (1.2 percent) (MOFA, 2003). Fisheries of Lake Volta are characterized by overfishing, and the use of illegal and unsustainable fishing gear due to the general lack of alternative livelihoods for fishers (Asiedu *et al.,* 2019).

Fishing methods

The fishing gear used in the Volta River varies seasonally, with fishers frequently shifting between different fishing methods depending on the water levels in the floodplains of the basin. Fishers around the lake have adapted an array of at least 27 different types of fishing gear. During water recession, the surface area of the reservoir decreases and fish migrate to deeper water, creating concentrations of fish biomass requiring specific fishing methods, such as *nifa-nifa* and *acadja* (types of brush parks, which use tree branches that act as fish aggregation devices). Illegal purse seine nets are the most common fishing method, with 47 percent of fishers using them and other encircling gear, which account for 60 to 70 percent of total fish landings on the lake (Asiedu *et al.,* 2019). Gillnets are also common, with a range of mesh sizes (25 to 100 mm). Other gear includes cast nets, seine nets, traps, hook and line and longlines, which target *Lates, Clarias* and *Bagrus* (van Zweiten *et al.,* 2011).

Fish trade

There are no formal estimations as to the value of the Volta River fisheries. According to Breuil (1995) the contribution of the fishery sector in Burkina Faso is only at a local level and contributes less than 1 percent to the gross domestic product (GDP). Nieland and Béné (2008) suggested that for a potential production of 16 000 tonnes/year, the fisheries in the Volta River Basin could be worth USD 8.32 million/year and for a potential production of 62 000 tonnes/year fisheries on Lake Volta could be worth USD 90.75 million/year.

Employment

Fishers on Lake Volta are generally full time, operating about 300 days/year and working 6 days to 6.5 days a week. The flooding of Lake Volta created a large fishery on which an estimated 300 000 people depend for their livelihood, of which 80 000 are fishers and 20 000 are fish processors (Braimah, 1995). The fishery is solely artisanal with about 24 000 canoes actively fishing the lake from about 2 000 fishing villages (Béné, 2007). Conversely, in Burkina Faso where fishing is not a traditional occupation, it is estimated that the fisheries sector provides direct livelihood support to about 11 000 households, 8 000 full-time fishers and 3 000 fish processors (Béné, 2007).

Estimated fisheries production

Estimated fisheries production for the Volta River is presented in Table 2-2. More than 90 percent of the inland freshwater fish in Ghana is produced in Lake Volta. The fish yield pattern showed an initial steady increase to 62 000 tonnes in 1969, followed by a decline and stabilization at around 40 000 tonnes in 1979. However, from 1994 the fishery catch began to rise again reaching 80 000 tonnes in the late 1990s. The increase in fishery landings is thought to be the result of the adoption of active gear such as winch nets.

Fish catches from the Volta River are likely to be underestimated. Fish catch monitoring was only carried out at the nine main markets on Lake Volta until 1977; since then, no reservoir-wide summaries have been made causing data quality to deteriorate (van Zweiten *et al.,* 2011). Béné (2007) suggested that there was an overestimation and underestimation of catch data. Double counting is a source of error, as fish that are unloaded at markets are first recorded and then taken to be processed and double counted when the catch returns to the market. Fish landings at smaller markets are not recorded, neither are the landings at spontaneous temporary markets. Additionally, production estimates are based on processed fish landings, which means that fresh weight needs to be calculated (de Graaf and Ofori-Danson, 1997). Béné (2007) suggested that current fish production only represents about a quarter of the actual fish production from the Volta River. Catch data are reported as total fish production figures without due adjustment to make up for the total number of waterbodies concerned. Based on this, an estimate of 251 000 tonnes from Lake Volta was proposed for the year 2000. Also, previous estimations based on stock assessments by de Graaf and Ofori-Danson (1997) suggested that the 60 000 tonnes reported from Lake Volta in 1997 should have been between 150 000 and 200 000 tonnes.

Table 2-2. Estimated fisheries production for the Volta River

Country/waterbody		Catch estimate (tonnes)	Year	Reference
Burkina Faso	Volta River	4 546	n/a	Van den Bossche and Bernacsek (1990)
	Bagré Reservoir	975	n/a	Béné (2007)
Ghana	Lake Volta	65 000	2000	MOFA (2006)
	Volta River	4 000	n/a	Van den Bossche and Bernacsek (1990)
Benin,	Oueme	5 700	1976	Welcomme (1979)
Benin, Togo, Burkina Faso	Oti River	1 870	1976	Van den Bossche and Bernacsek (1990)
Total		**82 091**		

Note: The Volta River estimates include the White and Black Volta.

Status of the fisheries: catch trends

The median daily catch rates of all gear were 25 kg/boat, with the annual catch per canoe at around 7.5 tonnes/year. With an average of two or three fishers per boat, this would realize a catch of 2.5 tonnes to 3.9 tonnes/fisher/year (Kolding and van Zweiten, 2006), which is within the range expected from an African freshwater fishery (Jul-Larsen *et al.,* 2003).

Fisheries production from Yeji fishing port on the lake witnessed a steady decline in catches from 14 000 tonnes in 2005 to 8 500 tonnes in 2015, with large interannual variability from a high of 25 000 tonnes in 2008 to just 2 000 tonnes in 2010 (Asiedu *et al.,* 2019). The sharp decline in fish production can be attributed to the construction of the Bui Dam on the White Volta (Asiedu *et al.,* 2019).

Assessments and reports conducted over the last 40 years claim that the lake resources are seriously overexploited and are steadily declining (Braimah, 1995; de Graaf and Ofori-Danson, 1997; Asiedu *et al.,* 2019). Independent studies and interviews with local fishers have suggested that the decline in fish catch volume is generally attributed to a reduction in total rainfall, an increasing fisher population, the use of illegal and unsustainable fishing methods and the development of fish farming along the banks of the lake that destroys brushes in which fish shelter (Béné, 2007; Asiedu *et al.,* 2019).

Aquaculture

In the past, aquaculture development in Burkina Faso was attempted, but resulted in costly failures in intensive tilapia farming (Miller, 2006). A German Cooperation (GTZ) project implemented from 1988 to 2002 aimed to increase fish production in the southwestern part of the country. The production of Nile tilapia increased from 50 kg/ha to 115 kg/ha but was still less than the initial objective. After 14 years GTZ concluded that culture-based fisheries in Burkina Faso were feasible, but upscaling of the practices was impeded by major bottlenecks relating to the high price of fingerlings and their low survival rate (World Bank, 2007).

By contrast, in Ghana the government implemented legislation and policies to support the growth of fish farming in 2013. Over 80 percent of production is locally selected Volta stocks of *O. niloticus*, the remainder being mostly African catfish (*Clarias gariepinus*) (Miller, 2006). Currently there are around 40 farms on Lake Volta (Hatchery International, 2014), but no estimates for the farmed fish production on Lake Volta are available.

Recreational fishing

Sport fishing is considered popular on the Volta River in Ghana, but figures on participation or quantity of fish caught are unavailable. Recreational fishing is conducted in the delta region of Lake Volta and some of the tributaries. The most popular species for freshwater anglers are Nile perch (*Lates niloticus*), giraffe catfish (*Auchenoglanis occidentalis*), African knifefish (*Gymnarchus niloticus*) and tigerfish *(Hydrocynus forskahlii*) (Ghana Investment Promotion Centre, 2017).

2.3 THREATS TO THE FISHERIES

Habitat modification

The change from riverine to lacustrine conditions during the formation of the lake led to the death of a variety of fish species, including *Chrysichthys* spp., which was very sensitive to oxygen depletion (Petr, 1968). The ecological change also brought about substantial changes in the fish community structure. During the lake's initial two years, some of the riverine species, especially Mormyridae, almost completely disappeared (Béné, 2007). However, the benefits of the creation of Ghana's largest fishery possibly outweigh the impact of the loss of these species on the livelihoods of fishers.

Overfishing

In 2006**,** the Ministry of Fisheries stated that Lake Volta was the most significant fishery in Ghana. However, the Lake Volta fishery is also considered open access, which the government has recognized as the main factor causing the overexploitation, overcapitalization and poor performance of the fishery that inhibits the optimum and sustainable use of the fisheries resources (Asiedu *et al.,* 2019).

It is often reported that fishers complain about a greater proportion of very small fish in their catches (Béné, 2007). Pittaluga *et al.* (2003) reported that 97 percent of fishers interviewed said that fish catches were declining. The primary reason for this, according to the fishers, had been the increased number of fishers, lower water level and the use of damaging fishing methods (Béné, 2007). The Fisheries Regulation 2010, stated minimum mesh size for seine nets as 2.5 mm, but even though 80 percent of fishers were aware of this regulation they continued to flout the law and use illegal purse seines and small mesh sizes, due to a lack of alternative livelihoods, resulting in intense pressure on Lake Volta fisheries (Asiedu *et al.,* 2019). This is supported by length frequency data on 26 commercially important fish species collected by the Integrated Development of Artisanal Fisheries Programme which indicated that 17 fish species commonly harvested were caught during their first year (Gougswaard and Avoke, 1993). Extensive fishing down and mortality of juvenile fish has been caused by extensive use of small-meshed gillnets (Béné, 2007).

2.4 EQUIVALENT FOOD REPLACEMENT

More than 90 percent of inland freshwater fish in Ghana is produced from Lake Volta, and fish and fishery products provide nearly 70 percent of Ghana's animal protein requirements. Given that fisheries from the Volta River, particularly Lake Volta, contribute towards the livelihoods of around 300 000 people, the loss of inland fisheries would have a detrimental impact on the fisher communities within the basin. Cost replacement discussion was based on a 50 percent loss in fisheries production from the production values in Table 2-2. The food replacement discussion will only deal with the countries for which catch estimates were reported (Burkina Faso, Ghana, Benin and Togo). Equivalent food replacement figures were estimated for aquaculture (tilapia), livestock (beef, pork and chicken) and maize (Table 2-3).

Table 2-3. Food production (tonnes), water (million m³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/ pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Tilapia	24 283 (54.7)	72.6 (6.0)	1 103 (0.7)	0.006
Beef	25 484 (12.9)	392.8 (32.5)	2 940 (1.9)	1.6
Pork	13 328 (18.4)	79.8 (6.6)	1 817 (1.1)	0.007
Chicken	41 974 (27.4)	181.5 (15.0)	1 126 (0.7)	0.1
Maize	53 932 (1.0)	65.9 (5.4)	96 (0.06)	0.002

Energy replacement (Table 2-3)

Aquaculture is not well developed in the Volta Basin countries and, as such, replacement of kilojoules from capture fisheries with tilapia would require the equivalent of 54.7 percent of current tilapia production (tilapia aquaculture was 44 380 tonnes in 2015). Over 97 percent of the current tilapia production comes from Ghana (43 300 tonnes) so to meet the demand for fish in the other basin countries would require substantial development of fish farming. Chicken production would have to increase by the 27.4 percent over current production (in 2014 chicken production was 153 216 tonnes).

Water demand (Table 2-3)

Beef production would require the largest water-use increase, equivalent to 32.5 percent of agricultural water use from the basin countries (agricultural water use was 1.2 km³ in 2016). Chicken production would require the second largest water demand, equivalent to 15.0 percent of agricultural water use from the basin countries. The remaining replacement food sources require similar amounts of water to replace capture fisheries such as maize, equivalent to 5.4 to 6.6 percent of agricultural water use.

Land requirement (Table 2-3)

Farmed tilapia would require substantial land conversion to replace capture fisheries, equivalent to 0.7 percent of the Volta River Basin area. As aquaculture practices are relatively undeveloped within the basin, an expansion in aquaculture practices and improvement in efficiency of current practices could see reduction in this figure. Beef production would require the largest land conversion, equivalent to 1.9 percent of the pastureland in the basin countries (pastureland area in 2014 was 158 500 km²). Maize would require an expansion of 96 km² to replace capture fisheries, equivalent to 0.04 percent of arable land in the basin (arable land area in 2014 was 160 500 km²).

Greenhouse gas emissions (Table 2-3)

Estimated carbon emissions from a 50 percent loss to capture fisheries from the Volta River were 154 333 tonnes. Net increase in carbon emissions from replacement of capture fisheries with replacement sources would be highest for beef (1.6 million tonnes), followed by chicken (0.1 million tonnes), pork (7 371 tonnes) farmed tilapia (6 318 tonnes) and maize (2 146 tonnes).

2.5 FISHERIES MANAGEMENT

National management strategies

Fisheries management strategies in Burkina Faso are not specifically aimed at fish stocks in the Volta River. General countrywide fishing management established in the Law for the Protection and Conservation of Fishery Resources in Burkina Faso includes prohibited fishing gear (electric fishing, driftnet fishing, baiting, construction of dykes, purse seines) and mesh size restrictions (gear below 35 mm mesh size). Legislation also sets out closed seasons and protected areas, which include spawning areas and the area up to 2 m from the shoreline (FAO, 2003).

In Ghana, fisheries are mainly managed under the Fisheries Act, 2002. However, fisheries law enforcement and adherence by fisher communities is generally weak. For instance, under the Fisheries Act, 2002, closed seasons can be implemented, but these are ignored and there is no off season of the closed season on Lake Volta.

Typically, fisheries management for Lake Volta is built around six strategic goals. The first is the use of Specially Protected Areas as breeding and nursery areas; enforcing fishery regulations; and introducing a licensing system to reduce the fleet size by 30 percent. The second goal is concerned with the harmonization and strengthening of the institutional environment for fisheries management and research. The third goal concerns the establishment of co-management institutions that can manage territorial use rights. The fourth goal is concerned with improving socio-economic conditions of lakeside communities as well as infrastructure. The fifth goal addresses an ecological environment that can sustain existing alternative livelihoods such as farming and livestock rearing. The final goal includes effective implementation of policy that reflects the Code of Conduct for Responsible Fisheries (FAO, 2004).

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3 LAKE CHAD BASIN

3.1 OVERVIEW

The Lake Chad Basin occupies about 8 percent of the surface area of Africa and is shared between eight countries (Table 3-1). Historically, Lake Chad covered an area of about 25 000 km^2 within four basin countries (Nigeria, Niger, Chad and Cameroon) (Ovie and Emma, 2011), but today the size of the lake covers about 2 000 km^2 and occupies about 1 percent of the basin (Coe and Foley, 2001; LCBC, 2017a). The lake is shallow (a mean depth of 4 m) (Carmouze *et al.,* 1983), making it very dynamic, with constantly changing size, shape and depth (Ovie and Emma, 2011). The lake itself is fed by one subsystem, the Chari–Logone rivers, which cover an area of about 650 000 km^2; they flow 1 400 km from the Cameroon Mountains and contribute about 95 percent of the Lake Chad Basin water (Ovie and Emma, 2011). The basin also receives water from the Komadugu–Yobe and Yedseram subsystems (UNEP GIWA, 2004). The Komadugu–Yobe system contributes less than 2.5 percent of the total inflow into Lake Chad and is the only perennial river that flows into the northern pool of Lake Chad. Areas of the basin in Chad, Central African Republic and Niger are characterized by rainfall instability and are prone to droughts (LCBC, 2017a).

Table 3-1. Characteristics of Lake Chad Basin

Country	Area of the lake basin (km^2)	Percent area of the lake in countries	Population of the lake basin	Population density/km^2
Algeria	90 391	3.67	16 249	0.2
Cameroon	48 003	1.95	3 149 456	66
Central African Republic	214 743	8.72	1 380 201	6
Chad	1 130 350	45.91	12 432 316	11
Libya	29 330	1.19	4 389	0.1
Niger	674 126	27.38	4 386 247	7
Nigeria	178 945	7.27	31 288 526	175
Sudan	95 951	3.90	3 004 329	31
Total	**2 461 839**	**100**	**55 661 715**	**37**

Fish diversity

There are various estimates for the ichthyological diversity of the Lake Chad Basin. Blache and Milton (1962) listed 140 species, Sagua (1991) listed 176 in the Chari–Logone–Lake Chad System and LCBC (2017b) reported between 120 and 140 species within the Lake Chad Basin. FishBase lists 165 species for the Lake Chad–Chari River system (FishBase, 2017). However, since the 1972/1973 drought there has been a considerable reduction in the number of species. The unstable, hostile environment of low water, high temperature and low dissolved oxygen that now dominates much of the ecosystem is favoured by wetland species such as *Clarias* catfish, tilapiine cichlids and *Heterotis* spp. that are better adapted to these conditions (Ovie and Emma, 2011).

3.2 FISHERIES OVERVIEW

There are three main groups of fishers active in the Lake Chad Basin: professional fishers who mainly come from abroad and mostly operate on the lake and other main waterbodies; non-professional fishers who fish seasonally in conjunction with other activities (agriculture, livestock rearing); and occasional fishers who fish as part of a subsistence livelihood. Fishing in Lake Chad is wholly artisanal and less than 1 percent of the fishing fleet is motorized (LCBC, 2017b). At least eight different waterbodies are used for fishing: small seasonal bodies of water, Lake Chad (open water), small permanent bodies of water, oxbow lakes, tributaries (Chari–Logone rivers), reservoirs, irrigations channels and floodplains (Jolley *et al.,* 2001; LCBC, 2017b). The floodplains and swamps are rich in organic matter and minerals and provide ideal conditions for fish breeding and growth (LCBC, 2017b).

Fishing methods

Depending on the depth of water, fish species available and fishers' wealth, a wide range of fishing methods are used within the basin and around 31 000 canoes are used for fishing. Dragnets and seine nets are the main fishing gear used by richer households (Béné *et al.,* 2003) or professional fishers (LCBC, 2017b). The most common fishing methods are gillnets (floating or fixed), traps, hook and line, longlines, cane traps, cast nets and mosquito nets (LCBC, 2017b).

Fish trade

Most of the fish caught in the Lake Chad Basin (80 percent) is exported to Nigeria where demand for fish is high (Jolley *et al.,* 2001). Various processing techniques include smoking, drying, charring and frying, but fresh fish is also sold. Preservation techniques tend to be favoured due to the hot climate and poor infrastructure. There is a huge demand for fresh fish in other regions of the basin, but supply is limited due to poor infrastructure linking fishing sites to urban centres and lack of cold storage facilities (LCBC, 2017b).

Employment

Specific employment by country for the Lake Chad Basin is not known, but Sagua (1991) and LCBC, (2017b) both estimated that the number of rural households (part time and full time) engaged in fishing activities to be as high as 200 000 people. However, this number does not include the many more thousands of people involved indirectly in fisheries through processing, selling, transporting and gear construction, for which the figure is estimated at around 10 million people (LCBC, 2017b).

Estimated fisheries production

Table 3-2 indicates the estimated fisheries production from Lake Chad in 2012 and the tributary rivers from the 1960s. Fisheries in Lake Chad are an important source of income for households and contribute towards food security. Previous estimates from 2003 suggested that fisheries production from Lake Chad was 119 377 tonnes (based on the volume of fish sold, dry weight converted to wet weight) with catches in Nigeria at 45 864 tonnes, Niger 37 840 tonnes, Cameroon 24 800 tonnes and Chad 10 873 tonnes (Nieland and Béné, 2004). Fish catches from Nigeria have comprised the largest portion of the catch (38 percent) followed by 32 percent from Niger, 21 percent from Cameroon and 9 percent from Chad (LCBC, 2017b). The value of Lake Chad fisheries increased from USD 55.2 million in 2007, with 47 percent of the value from Nigeria (Nieland and Béné, 2004), to USD 220 million in 2012 (approximately100 000 tonnes) (FAO, 2017).

There are comparatively few time series data on the Lake Chad Basin due to a lack of continuity in the operation of information-gathering systems. Armed conflict and political instability in the region since the 1970s led to the withdrawal of national and international research and an almost total interruption of monitoring activities in the area (Jolley *et al.,* 2001; Béné *et al.,* 2003). Consequently, the basin suffers from an information deficit and FAO considers the national statistics for this region to be unreliable and incomplete (Béné *et al.,* 2003). As such, fisheries production estimates in Table 3-2 may not be an accurate representation of the state of fisheries in the basin, particularly for the Chari and Logone rivers, for which recent fisheries catch estimates are lacking.

Table 3-2. Estimated fish production from the Lake Chad Basin

Country	Catch estimate (tonnes)	Year	Reference
Cameroon	21 000	2012	LCBC (2017b)
Chad	9 000		
Niger	32 000		
Nigeria	38 000		
Lake total	**100 000**		
Chari River	20 000–30 000	1960s	Blache and Milton (1962)
Logone River	35 000		
River total	**55 000–65 000**		
Total	**160 000**		

Note: The Chari River value used in the total was an average of the two values (25 000 tonnes).

Status of the fisheries: catch trends

The unpredictable hydrological cycle in the Chad Basin has meant difficulty in estimating fish stock size and yield. According to Durand (1973) from 1963 to 1971 fisheries landings increased from 20 000 tonnes to over 100 000 tonnes because of an expansion in commercial trade with Southern Nigeria. From 1971 to 1974, fish landings increased at a higher rate reaching 220 000 tonnes in 1974 when the lake had greatly diminished in size due to the Sahel drought and fish stocks were increasingly concentrated and easier to catch (Durand, 1980). Since the 1972/1973 drought there has been a considerable reduction in species diversity of the lake, with species having adapted to survive high temperatures and low dissolved oxygen in the emerging swampland (Ovie and Emma, 2011). The continued reduction in the lake's size since 1980 and emergence of large areas of swampland led to the creation of swamp fisheries for *Clarias* catfish and *Tilapia* spp. (Nieland, 1992). Prior to 1970, a small sardine-like fish (*Alestes baremose*) that occupied both the lake and riverine channels was highly abundant in the lake catch. However, the reduction in lake size and expansion of swampland did not favour the *Alestes* and disrupted its spawning cycles (Nieland, Madakan and Béné 2005).

Aquaculture

Aquaculture is not currently well developed in the Lake Chad Basin, but small- and medium-scale aquaculture activities are considered important adaptive strategies to supplement declining fisheries from the lake basin. Aquaculture practices are slowly emerging in Niger, Nigeria and Cameroon. Aquaculture is widely seen as a potential option for increasing fish production, consumption, income and creating jobs in the Lake Chad Basin (Ovie & Emma, 2011).

3.3 THREATS TO THE FISHERIES

Climate change

The shoreline of Lake Chad has drastically diminished since the 1960s, where standing water of the lake covered 23 000 km^2, but recurrent droughts that have affected the basin since 1973 have meant that the current size of the lake was a fraction of its former size at 1 350 km^2 in 2001 (Ovie and Emma, 2011). For 40 years, the lake waters have only been present in the southern pool and surrounding marshland. Lake Chad's northern pool remained dry from 1976 to 2008 (LCBC, 2017b). The relatively flat and dynamic nature of the lake means that small variations in water levels can flood large areas or see the shoreline retreat by several kilometres. Low water levels alter the physical environment and can lead to changes of fish species at both an individual and population level, by affecting spawning larval dispersal and recruitment. Lower flows constrained the seasonal migration of *Alestes* spp. and the other highly valued commercial pelagic species *Lates* and *Hydrocynus* (Nieland, Madakan and Béné, 2005) through destruction of nursery grounds, particularly on the Yares floodplain. Climate conditions saw a shift in species composition to *Clarias* catfish, which now dominate the commercial fisheries in the area, as they are more adapted to swampland conditions and can even breathe air through auxiliary gills (Nieland, Madakan and Béné 2005). Temperature increases of 3.5 °C are projected for the river basin by 2080/2099 (ECOWAS-SWAC/OECD, 2008) and further reductions in lake area would force fishers to diversify their livelihood activities and move into farming due to uncertainties caused by varying water levels of the lake (LCBC, 2017b).

3.4 EQUIVALENT FOOD REPLACEMENT

Lake Chad plays a hugely important role in ensuring food security for the countries of the Lake Chad Basin. In times of economic crisis, such as crop failure, artisanal fisheries provide alternative and vital sources of livelihoods to rural households (Nieland and Béné, 2004). Over 80 percent of the rural population in the region is dependent on fish as the commonest and cheapest source of animal protein. The fertility of Lake Chad's soils has meant that family farming of cereal crops has expanded in the basin where the water levels have receded (LCBC, 2017b).

Given that Lake Chad fisheries contribute to the food and nutritional security of over 10 million people, the loss of capture fisheries would be hugely detrimental to the basin countries. Alternative livelihood options may not be suitable and the increasing aridity of the climate could mean that livestock and agriculture may not produce enough food to meet demand. Replacement estimates were established for a 50 percent loss to the Lake Chad Basin fishery catch (Table 3-2). Replacement food sources consist of aquaculture (tilapia), livestock (beef, pork and chicken) and crops (rice and maize).

Table 3-3. Food production (tonnes), water (km^3), land (km^2) and net increase in carbon emissions (million tonnes) required to replace kilocalories from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilocalories from fisheries (percentage of current food production)	Water required to replace fisheries in km^3 (percentage of agricultural water use)	Land required to replace fisheries in km^2 (percentage of inland water area/ pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Tilapia	47 329 (151.5)	0.14 (0.8)	2 151 (0.009)	0.01
Beef	49 670 (4.0)	0.77 (4.4)	5 731 (0.3)	3.11
Pork	25 977 (8.3)	0.16 (0.9)	3 542 (0.2)	0.01
Chicken	81 809 (9.7)	0.35 (2.0)	2 195 (0.1)	0.19
Rice	69 538 (0.9)	0.16 (0.9)	152 (0.02)	0.007
Maize	102 115 (0.8)	0.13 (0.7)	187 (0.02)	0.004

Energy replacement (Table 3-3)

Maize as replacement food source would require the largest increase in production, equivalent to 0.8 percent of current production from the Lake Chad Basin countries (maize production in 2014 was of 13 million tonnes from the basin countries). Replacement of capture fisheries with chicken would require 81 809 tonnes, equivalent to 9.7 percent of production from the Lake Chad Basin countries (production in 2014 was 846 000 tonnes). Aquaculture practices within the basin countries are not well developed. Farmed tilapia replacement is equivalent to 151 percent of current production (tilapia aquaculture production in 2015 was 31 235 tonnes).

Water demand (Table 3-3)

Replacement of capture fisheries with beef production would require the largest water demand, equivalent to 4.4 percent of the total agricultural water usage from the Lake Chad Basin countries (water use was 17.2 km^3 in 2000-2017). Chicken production would require about half the water demand compared to beef production, equivalent to 2.0 percent of the agricultural water usage from the Lake Chad Basin. The remaining replacement food sources require a similar water demand ranging from

0.13 km^3 to 0.16 km^3, equivalent to 0.7 percent to 0.9 percent of agricultural water usage from the Lake Chad Basin.

Land requirements (Table 3-3)

Beef production would require the largest land conversion, equivalent to 0.3 percent of the pastureland area from the Lake Chad Basin countries (pastureland area from Lake Chad countries was 1.06 million km^2). Farmed tilapia would require land conversion, equivalent to 0.009 percent of the area of Lake Chad Basin, just under the total size of the lake area itself. Rice and maize crops would require 152 km^2 and 187 km^2 of land to replace capture fisheries respectively. This is equivalent to 0.02 percent of arable land within the basin (arable land area was 918 125 km^2 in the basin countries).

Greenhouse gas emissions (Table 3-3)

Estimated carbon emissions for 50 percent of the capture fisheries from Lake Chad were 300 800 tonnes. Net increases in carbon emissions from the replacement of capture fisheries with alternative food sources would be lowest for rice and maize crops (0.007 million tonnes and 0.004 million tonnes). Net increases in carbon emissions for livestock would be highest for beef (3.11 million tonnes), chicken (0.19 million tonnes) and pork and tilapia (0.001 million tonnes).

3.5 FISHERIES MANAGEMENT

Three types of fisheries management predominate in the Lake Chad Basin: traditional systems (informal); modern or centralized systems (formal); and mixed systems. Traditional systems are those operated by traditional authorities (district or village heads and chiefs) who enforce fishing regulations. Central governments administer modern systems and officers of the state enforce fishing regulations. The mixed systems involve the participation (intentionally or inadvertently) of both traditional and government institutions (Nieland *et al.,* 2000).

National management strategies

In Niger, management measures are based on Law No. 98-042, 1998. The law determines fishing rules and sets out regulations including the use of fishing licences and bans on gear such as seine nets, nets with mesh size less than 6 inches as well as the use of explosives or poisons.

In Cameroon, fisheries management measures include routine monitoring by agents of the Ministry of Livestock, Fisheries and Animal Industries; collection of fisheries statistics at fish preservation depots; and infrastructure development (sales halls, ice plant units, smokehouses).

In Chad, joint management of Lake Chad is implemented by the Local Authority for Orientation and Decision and the Village Surveillance Committee. In essence the surface area of water of Lake Chad is split into integral protection zones (where all activities are prohibited, only experimental fishing is permitted), and Fisheries Protection Zones (which allow fishing depending on areas and in accordance with local communities).

There is currently no formal management measure in practice in Nigeria, but some traditional management measures have been put in place by traditional institutions (AU-IBAR 2015).

Management plan of the Lake Chad Fisheries

The Management Plan of the Lake Chad Fisheries, which was initiated in 2013, was implemented to integrate environmental, human and governance factors, with the involvement of all stakeholders in the management process to improve the well-being of fishing communities. In conjunction with principles based on the Ecosystem Approach to Fisheries, the management plan aims to ensure sustainable exploitation of Lake Chad Fisheries and contribute towards food security, poverty alleviation and income enhancement at all levels. The management objectives for the plan include: sustainable exploitation of fisheries and protection of ecosystems; to improve the living and working conditions, and income of fishers; and improve concerted management of fisheries (AU-IBAR 2015).

The plan has 12 operational objectives, including:

- Improving the selectivity of fishing gear;
- Improving systems of information collection on catches and fishing effort;
- Introducing fishing closure periods and creation of no-entry zones;
- Improving fishing communities' access to basic social services; and
- Reducing the vulnerability of fishing communities to climate change through local adaption plans.

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4 SENEGAL RIVER

4.1 OVERVIEW

The Senegal River is the second largest river in West Africa after the Niger River. It is formed by the confluence of the Bafing and Bakoye rivers in Mali and flows for 1 08 km into the Atlantic Ocean. At 760 km long, the Bafing River rises from the Futah Jallon Mountains in Guinea and contributes more than 50 percent of the average flow to the Senegal River (≈800 m^3/s). The Bahkoye rises from the Mandingo Plateau in Guinea and flows for 560 km. After the two rivers meet at Bafulabe, the Senegal River receives inflows from various tributaries, the largest being the Falemé River, which forms a natural border with Mauritania. The Senegal River Basin can be categorized into three sections: The Upper Basin, The Valley and The Delta. The Valley region is an alluvial plain that forms a 10 km- to 20- km floodplain. Two dams, the Diama (Senegal) and the Manantali (Mali), which are built on the Bafing River (AU-IBAR 2015), control the flow of the Senegal River.

Table 4-1. Characteristics of the Senegal River

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
Mauritania	197 134	41	1 933 924	10
Mali	171 603	36	3 070 060	18
Senegal	77 071	16	2 384 347	31
Guinea	31 482	7	929 224	30
Total	**477 291**	**100**	**8 317 555**	**22**

Fish diversity

According to FishBase (2017) there are 144 species in the Senegal River, the most abundant families being Cyprinidae (23 species), Mormyridae (12 species), Cichlidae, Alestidae and Mochokidae (11 species each). There are two endemic species: *Enteromius ditinensis* and *Synodontis tourei*. There are no documented fish introductions.

4.2 FISHERIES OVERVIEW

The fisheries sector of the basin provides a significant contribution to socio-economic life, food security, employment and export revenues and is the main fish supply to the member states. After agriculture, fishing is the largest economic activity of the basin. Fishers operate in the rivers during the dry season and on the floodplains during the wet season when fish migrate to feeding and spawning grounds. The volume and catch of fish year on year depends on the water level on the floodplain. The Manantali Reservoir is Mali's third largest fishing area after the Niger Inner Delta and Selingue Reservoir. Catch composition comprises around 20 species, which account for over 90 percent of the landings; the predominant commercial species are Nile tilapia (*Oreochromis niloticus*), Nile perch (*Lates niloticus*) silur or catfish (*Clarias gariepinus, Heterobranchus longifillis*) and African carp (*Labeo coubie*) (AU-IBAR, 2015). Cheikh Oumar *et al.* (2006) found that 40 percent of catches constituted cobo (*Ethmalosa fimbriata*) and tilapias made up 30 percent of the catch.

Fishing methods

About 90 percent of the total fishing effort relies on just four types of fishing gear: encircling gillnets, beach seine nets, cast nets and surface drift nets (Cheikh Oumar *et al.,* 2006).

Fish trade

A significant portion of the catch is sold in processed form, such as dried, smoked or fried. Port harvest losses are high due to poor infrastructure and account for 20 percent to 25 percent of the harvest. The distribution of freshwater fish products is concentrated around large trading centres. The lack of refrigeration infrastructure is the biggest constraint for the commercialization of freshwater fish from the Senegal River Basin (Cheikh Oumar *et al.,* 2006). Valuation estimates made by Nieland and Béné (2008) estimated the value of fisheries production from the Senegal River to be USD 16.78 million (based on annual catch of 30 500 tonnes).

Employment

It was estimated that in the 1970s, around 10 000 fishers were working full time and as many were working part time, accounting for 6.1 percent of the active population of the basin then (Reizer, 1974). According to AU-IBAR (2015) fishing is the main source of income for more than 6 300 fishers and close to 2 300 fishers depend on fishing as a supplementary source of income. These fishers comprise 79 percent in Senegal (6 794), 16 percent in Mauritania (1 376) and 3 percent in Mali (258) (AU-IBAR 2015).

Estimated fisheries production

Table 4-2 indicates the estimated fisheries production for the Senegal River. There is insufficient information from nominal fishery statistics, at an administrative or academic level, to establish trends in inland capture fisheries in the Senegal River. Annual fisheries catch estimates of between 26 000 and 47 000 tonnes/year have been recycled by UNESCO-WWAP (2003), Nieland and Béné (2008) and AU-IBAR (2015). A study conducted by Cheikh Oumar *et al.* (2006) estimated that annual catches for the Senegal River were around 30 540 tonnes, however this is an underestimation as fish kept for home consumption (estimated at 5 percent to 10 percent of the total catch) were not included. The fishery sector in the Senegal River would appear to be under threat, as for several years now there has been a steady drop in the tonnage caught from the river in Mali, Mauritania and Senegal (UNESCO-WWAP 2003), although there are no figures to corroborate this. Some observers link the fishery decline to river development projects (e.g. dam construction) and their impact on the environment (increased salinity, eutrophication and proliferation of floating weeds) (UNESCO-WWAP 2003).

Table 4-2. Estimated fisheries production for the Senegal River

Catch estimate (tonnes)	Year	Reference
30 540	2005	Cheikh Oumar *et al.* (2006)

Status of the fisheries: catch trends

Trends in the Senegal River are virtually impossible to establish, as there are no historical time-lapse data and a general lack of up-to-date information on the inland fishery. According to AU-IBAR (2015) the construction of dams within the basin has led to changes in fish stocks and fish catches, but UNESCO-WWAP (2003) stated that although some old species had disappeared, new fish species have emerged.

Aquaculture

Fish farming projects have not yielded positive results in the Senegal River Basin due to the absence of monitoring and coordination, despite individual initiatives that have been carried out. Despite its potential, aquaculture activities have changed little over the last two decades and remain inefficient due to unfavourable ecological and socio-economic conditions (AU-IBAR, 2015).

Recreational fishing

Recreational fishing and fishing tourism potential in the Senegal River is just beginning to be realized. As such, there is no information regarding the scale of participation or the level of catch. But Nile perch is stated to be the prime target in the Senegal River (World Sport Fishing, 2015).

4.3 THREATS TO THE FISHERIES

Habitat modification

Since the 1980s, the Senegal River has become increasingly engineered with the building of embankments, irrigation and sluice gates, which have been developed in connection with the construction of the Manantali and Diama dams located near the mouth of the river in Senegal (Dumas *et al.,* 2010). Increased levels of salinity downstream of the Diama Dam in the delta region have led to a decline of 50 percent to 70 percent of fish stocks. There has also been a substantial decrease in fishery production in the middle valley following disruption to the annual flood cycle on the alluvial plain, which is one of the principal areas for fish reproduction (AU-IBAR, 2015). After the construction of dams, the number of fishers declined from 10 000 in 1970 to 2 500 in 1996, and fishery production declined from 40 000 tonnes to 10 000 tonnes annually (N'Diaye, Bouvier and Waaub, 2007). There was a redistribution of fishery resources following the construction of the dams – fishery production in the Manantali Reservoir increased in conjunction with fisheries from the Lac du Guiers, but catches from the valley declined, with an annual net loss of 11 250 tonnes (AU-IBAR, 2015).

Climate change

Mean annual temperatures increased 0.5 °C between 1960 and 2006, and across West Africa climate change projections predict temperature increases of 3 °C to 4 °C by 2100. In Senegal, the annual temperature is expected to increase by up to 3 °C by 2060 and 5 °C by 2090, with the projected warming rate being higher in the interior regions, which could result in higher magnitudes of droughts (ANACIM-WFP, 2013). Salinization has also increased because of drought and sea-level rise and has been attributed to the loss of fisheries production. Projections indicate that sea levels could rise by about 1 m by 2100, which could potentially inundate 6 000 km^2 of land or 8 percent of the Senegal land area. Initial estimates suggest that that up to USD 700 million-worth of infrastructure would be at risk, and up to 180 000 people could be displaced (ANACIM-WFP, 2013).

4.4 EQUIVALENT FOOD REPLACEMENT

Fishing is the largest economic activity after agriculture, particularly for people living near the river in The Valley. Fish consumption is high, particularly in Mali where per capita consumption in 2013 was 6.14 kg/capita/year (FAO, 2017). In addition, the Senegal River fisheries are of vital importance in Mauritania as the river is the only major inland fishery in the country. However, there are significant knowledge gaps regarding the fisheries data within the basin, as such equivalent replacement estimates would be based on a 100 percent loss to the total fishery value in Table 4-2. Replacement food sources consist of aquaculture (tilapia), livestock, (beef, pork and chicken) and rice.

Table 4-3. Food production (tonnes), water (million m^3), land (km^2) and net increase in carbon emissions (thousand tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million km^3 (percentage of agricultural water use)	Land required to replace fisheries in km^2 (percentage of inland water area/ pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (thousand tonnes)
Tilapia	18 068 (676.5)	54.1 (0.6)	821 (0.2)	4.70
Beef	18 961 (5.5)	292.3 (3.4)	2 187 (0.2)	1 187.13
Pork	9 916 (51.2)	59.4 (0.7)	1 352 (0.1)	5.48
Chicken	31 320 (24.4)	135.1 (1.6)	838 (0.1)	73.97
Rice	26 546 (0.5)	59.1 (0.7)	58 (0.04)	3.04

Energy replacement (Table 4-3)

Aquaculture from the Senegal River Basin countries has struggled to be established. Replacement of kilojoules of fish catch from the Senegal River with tilapia would be the equivalent of 676.5 percent of the 2015 production levels (farmed tilapia production was 2 671 tonnes). Pork production would require 51.2 percent of current production levels to replace fisheries (2014 pork production was 19 385 tonnes). Chicken production would require the largest replacement value, equivalent to 24.4 percent of current production.

Water demand (Table 4-3)

Beef replacement would have the largest impact on water resources equivalent to 3.4 percent of agricultural water withdrawals from the riparian countries required (agricultural water use was 8.7 km^3 in 2001-2004). Chicken production would require roughly half the water demand that beef production would require, equivalent to 1.6 percent of agricultural water use for the riparian countries. The remaining replacement food items would require similar water replacement values, equivalent to 0.6 percent to 0.7 percent of agricultural water use from the riparian countries.

Land requirements (Table 4-3)

Farmed tilapia production would require land conversion, equivalent to 0.2 percent of the Senegal River Basin area (Table 4-12). Rice production would require 58 km^2 of land to replace capture fisheries, equivalent to 0.04 percent of the arable land in the riparian countries (the arable land area in 2014 was 131 610 km^2).

Greenhouse gas emissions (Table 4-3)

Estimated carbon emissions from capture fisheries from the Senegal River were 114 830 tonnes. Replacement of 100 percent of capture fisheries would result in a net increase in carbon emissions, the largest coming from beef replacement (1.2 million tonnes), followed by chicken production (73 973 tonnes), pork production (5 484 tonnes), farmed tilapia (4 700 tonnes) and maize (3 044 tonnes).

4.5 FISHERIES MANAGEMENT

National management strategies

Mauritania and Senegal have adopted the Code of Conduct for Responsible Fisheries. In Senegal, fisheries have been governed by Law No. 67, 1970, which includes the code of conduct. However, these laws are being reviewed. Currently in Senegal, fisheries policy is governed by the Strategy Sustainable Development of Fisheries and Aquaculture, 2001, which grants powers to introduce fishing rights (AU-IBAR, 2015).

Transboundary fisheries management

The Organization pour la Mise en Valeur du fleuve Sénégal (OMVS) is a collaboration between Mali, Mauritania and Senegal and was established in 1972 to develop the Senegal River and share its resources. The goal of the OMVS is to foster the economic development in the Senegal River Basin through international cooperation. Some of the organization's main objectives are:

- To attain food self-sufficiency for the basin inhabitants;
- To contribute to the three countries' development through subregional cooperation; and
- To reduce economic vulnerability to climatic fluctuations (AU-IBAR, 2015).

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5 GAMBIA RIVER

5.1 OVERVIEW

The source of the Gambia River is in the Fouta Djallon Plateau in Guinea and it flows for 1 270 km through Senegal and Gambia to the Atlantic Ocean (Albaret *et al.,* 2004). The Gambia River is one of the last major river systems (longer than 1 000 km) in Africa to remain free flowing (WWF, 2006). The Gambia Estuary is also the last in West Africa that is free from extensive human disturbance and retains a normal salinity gradient (Albaret *et al.,* 2004). The river is divided into three sections, the Lower, Middle and Upper Gambia River. The Lower Gambia, which encompasses the whole of Gambia, has only 1 -m altitudinal difference over the last 500 km, hence tidal effects can be observed as far as 200 km from the river mouth (Webb, 1992; Louca *et al.,* 2008). The Middle Gambia lies entirely within Senegal, spanning a length of 480 km from the planned dam at Sambangalou and Kédougou (Senegal). The Upper Gambia (290 km long) is separated at the middle reach by a series of rapids and extends to the source (Daget, 1960). The estuary is defined by strong seasonality in salinity resulting in a dynamic mix of marine, estuarine and freshwater fish species in the main channel (Albaret *et al.,* 2004). The most important tributaries are the Sandougou, Koulountou, Nieri Ko and Niokolo Koba rivers (Blažek *et al.,* 2012). In the middle and lower Gambia, an extensive floodplain is associated with the river, of which a large portion forms the Niokolo Kona National Park. Floodplain habitats of the river are seasonally inundated and temporary pools disappear annually. Oxbow lakes are connected to the main river channel during peak discharge but remain isolated for much of the year (White, Ondracková and Reichard 2012).

Table 5-1. Characteristics of the Gambia River

Country	Area of the river basin (km²)	Percent area of the river in countries
Gambia	10 920	14
Senegal	55 380	71
Guinea	11 700	15
Total	**78 000**	**100**

Fish diversity

The fish fauna of the Gambia River is described as Nilo–Sudanian, with the upper river colonized mainly by Guinean species, but it has relatively low species diversity compared to the Senegal and Niger rivers (Leveque, Paugy and Teugels 1991). The lower reaches contain many estuarine and marine species that migrate up-river seasonally (Baran, 2000). According to FishBase (2017) there are 131 species in the Gambia River and one endemic species; the most abundant families are Cyprinidae (13 species), Mormyridae (12 species) and Cichlidae (11 species). Blažek *et al.* (2012) found 62 species in the Niokolo Koba National Park; Albaret *et al.* (2004) found 77 fish species in the estuary, which comprised marine, brackish and freshwater species.

5.2 FISHERIES OVERVIEW

The middle area of the river is popular for subsistence and small-scale commercial fishing and has become a focal point for fishers from Gambia's interior and for foreign fishers from Senegal, Mali and Guinea. Gambia fisheries are considered to be artisanal and non-industrial but some subsistence operators sometimes sell to industrial companies (Njie and Mikkola, 2002; Lesack, 1986). The freshwater part of the river contains various economically important fish species. The most abundant are tilapia (*O. niloticus*), African bony tongue (*Heterotis niloticus*) and catfish (*Synodomtis gambensis, Clarias gariepinus, Chrysichthus furcayu* and *Auchenoglanis occidentalis*). The lower portion of the river is brackish and marine fish are common, particularly bonga (*Ethmalosa* spp.), sea catfish, threadfins, barracuda, sole and shrimp. During the 1980s in the artisanal fishery in the lower reaches, 11 fish species made up 97 percent of the catch by weight. Fishery of the lower reaches typically operates after the rainy season (end of

October), with peak catches slightly before the onset of the heavy rains in July. Catches usually decline thereafter as the salt front is pushed downstream by increasing river discharge (Lesack, 1986). In the upper reach, 12 species constitute 90 percent of the catch by weight and *Tilapia* spp. *Clarias* spp. and *Chrysicthys nigrodigitatus* were the most abundant species in the Central River division.

Fishing methods

The five dominant fishing techniques are stow nets, gillnets, hook and line, surrounding nets and cast nets. Gillnets consist of a mixture of bottom set, floating and drifting gillnets and various traps are also used. The hook and line gear consists of various longline techniques and simple hand lines. Only 10 percent of canoes are motorized. Census figures indicate that 40 percent of the fishing vessels in Gambia are used by foreign fishers, mainly from Senegal (Lesack, 1986).

Fish trade

All fishing activities in Gambia contribute an average 3 percent of the GDP (FAO, 2007); Nieland and Béné (2008) estimated that the fish catch from the 1980s (1 400 tonnes to 3 500 tonnes) was worth an ex-vessel value of USD 4.4 million, with an additional USD 2.72 million generated through exports (Nieland and Béné, 2008). The market system in Gambia is complex due to the range of different markets served and the assortment of products offered. Fresh and hot smoked fish products tend to serve urban markets, and smoked, dry and low moisture content fresh fish serve rural and regional export markets, while hot smoked *Ethmalosa* spp. serve the European and United States markets (FAO, 2007). Generally, difficulties in marketing and the lack of fish processing and preservation infrastructure are considered major constraints to fishing in Gambia (Laë *et al.,* 2004).

Employment

The number of fishers in the Gambia River was estimated by Laë *et al.* (2004) at around 3 000, 83 percent of whom operated within the Gambia River Estuary; this included full-time and part-time fishers. According to FAO there are roughly 6 000 fishers throughout Gambia (both marine and freshwater) and 32 000 people are involved in the secondary sector (processing, trading, marketing and handling) (FAO, 2007). Gender involvement in fisheries in the Gambia River is not known, but about 60 percent of the secondary sector workforce is thought to comprise women (FAO, 2007). These values are likely an underestimation to the actual number of fishers in the basin, as figures may not account for the number of foreign fishers who are highly migratory.

Estimated fisheries production

Estimated fisheries production from the Gambia River is outlined in Table 5-2. The figures in Table 5-2 do not differ greatly from historical fishery estimates. Between 1977 and 1982, the annual catch from the Gambia River varied from 1 400 tonnes to 3 500 tonnes and Welcomme (1979) estimated the potential yield to be between 2 000 tonnes and 8 000 tonnes. Lesack (1986) also estimated that the fishery catch from the Gambia River was 2 700 tonnes in 1980. According to FAO (1999) inland fisheries catches from 1984 to 1999 were consistently between 2 700 tonnes and 2 400 tonnes annually. The fishery estimates presented in Table 5-2 by Laë *et al.* (2004) do not differ from historical estimates. Just under half of the catch (49 percent) came from the estuary. Stow nets were the most productive gear, accounting for 50 percent of the total production. Two taxa represented half of fish landings: *Polydactylus quadrifilis* (26 percent) and *Arius* spp. (20 percent), which are caught by handlines, longlines and drift nets (Laë *et al.,* 2004).

There is no official monitoring of fisheries in Gambia, which makes it difficult to obtain reliable estimates of fishing effort and catches. There are no official time series data and the only studies conducted on the state of fisheries in the Gambia River are those in scientific journals. Therefore, the figure in Table 5-2 is likely to be an underestimation of the actual catch levels in the Gambia River.

Table 5-2. Estimated fisheries production for the Gambia River

Catch estimate (tonnes)	Year	Reference
2 350	2001–2002	Laë *et al.* (2004)

Status of the fisheries: catch trends

The static nature of fisheries catches since the 1970s indicates either that fisheries are at a maximum yield or that the statistics are unreliable. Laë *et al.* (2004) found that early estimates of fishing effort in the Gambia River were sustainable, but were likely to increase due to political instability in the Guinea-Bissau and Casamance regions, which has forced Senegalese fishers to find safer fishing areas. Fishing activities are mainly concentrated on a few species that are commercially profitable: *Polydactylus quadrifilis*, *Arius* spp. and *Cynoglossus* spp. Annual catches for the Gambia Estuary are low for such a large estuary and average catch length is high ranging from 300 mm to 600 mm for the main species captured. These findings suggest low levels of exploitation (Laë *et al.,* 2004).

Aquaculture

The first attempt to introduce aquaculture to Gambia occurred in the 1970s and 1980s and focused mainly on small-scale tilapia production. This was short-lived but provided practical experience in fish culture. Renewed interest in aquaculture began again in 2008, with a UN-FAO-sponsored review of fisheries. Pond aquaculture construction began in 2010 in the Sapu region of the basin and was stocked with Nile tilapia, African catfish and African knifefish. As of 2011, all the tilapia produced is being sold or consumed locally, although no details about production quantities are available (Rice *et al.,* 2012).

Recreational fisheries

Since the early 1990s, the popularity of sport fishing has increased on the Gambia River. The unspoiled nature of the river and variety of fishing locations (deep channels, sunken trees and rocky outcrops) have made sport-fishing on the Gambia River hugely popular. The Fisheries Act, 1991 requires that a licence should be obtained for sport fishing (FAO, 2007). Popular angling fish are tigerfish, vundu catfish, sharptooth catfish, Zambezi pike, characins, threadfin salmon and many more (Gambia Sport Fishing Guide, 2017).

5.3 THREATS TO THE FISHERIES

Habitat modification

The Sambangalou hydropower project is in the final stages of financial negotiations before construction work can begin. The dam would be situated on the border of Senegal and Guinea in the middle reaches of the Gambia River. Predictions of the impact of the dam range from positive to negative. Mangrove forests in the Lower Gambia provide important nursery and breeding areas for many fish species in the Gambia River (Degeorges and Reilly, 2007). The construction of the dam would lead to a major dieback and inland shift of mangroves, and more salt-tolerant *Avicennia* would replace the more productive *Rhizophora* forests (Snedaker, 1984). The impact on fisheries is variable. The life cycles of an estimated 33 species of fish depend, either directly or indirectly, on the mangrove ecosystem. A cost–benefit analysis of the Sambangalou Dam stated that the construction of the dam would have positive effects for fisheries in the Gambia River Valley, with benefits in terms of employment (+700 fishers), annual fish catches (+560 tonnes) and added value (+EUR 1 473 000). Also, the creation of a fishing reservoir could create 1 000 fishing jobs and an 891-tonne increase in catch. But areas downstream of the dam would be affected with an initial decline in fisheries, and shrimp fishing would no longer be possible in some areas where it is currently conducted (Hamadé, 2012).

5.4 EQUIVALENT FOOD REPLACEMENT

Given the relatively static nature of fish catches since the 1970s and the low exploitation level and sustainable fishing effort, equivalent replacement estimates were established for a 100 percent loss to the Gambian River fishery (Table 5-3). Replacement food sources are aquaculture (tilapia), livestock (beef, pork and chicken) and rice.

Table 5-3. Food production (tonnes), water (million m^3), land (km^2) and net increase in carbon emissions (thousand tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m^3 (percentage of agricultural water use)	Land required to replace fisheries in km^2 (percentage of inland water area/pastureland or agricultural land	Additional greenhouse gas emissions from replacement of fisheries (thousand tonnes)
Tilapia	1 390 (192.3)	4.15 (0.2)	63 (0.1)	0.36
Beef	1 459 (0.9)	22.49 (0.9)	168 (0.1)	91.34
Pork	763 (4.5)	4.56 (0.2)	104 (0.06)	0.42
Chicken	2 403 (3.0)	10.39 (0.4)	64 (0.04)	5.69
Rice	2 042 (0.08)	4.56 (0.2)	5 (0.007)	0.23

Energy replacement (Table 5-3)

Aquaculture from the Gambia River Basin is not well developed; as such to replace kilocalories from capture fisheries with farmed tilapia would require a 192.3 percent increase in current production (2015 production was 723 tonnes from the basin countries). Pork would require the smallest production levels, equivalent to 4.5 percent of current production levels (2014 production was 16 910 tonnes). Chicken production would require the largest increase in production to replace fisheries, equivalent to 3.0 percent of current production (2014 production was 79 933 tonnes).

Water demand (Table 5-3)

Beef production would require the largest water demand to replace capture fisheries of 22.49 million m^3, equivalent to 0.9 percent of agricultural water use from the riparian countries (agricultural water use was 2.4 km^3 in 1999-2002). Pork, rice and farmed tilapia would require a similar water demand of 4.15 to 4.56 million m^3, equivalent to 0.2 percent of agricultural water use in the riparian countries.

Land requirements (Table 5-3)

Farmed tilapia production would require land conversion of 63 km^2 to replace capture fisheries production, equivalent to 0.1 percent of the Gambia River Basin area. Beef production would require the largest land conversion of land, equivalent to 0.1 percent of pastureland in the riparian countries (the pastureland area in 2014 was 164 600 km^2). Rice production would require 5 km^2 to replace capture fisheries, equivalent to 0.003 percent of arable land in the riparian countries (the arable land area in 2014 was 67 400 km^2).

Greenhouse gas emissions (Table 5-3)

Estimated carbon emissions from the capture fisheries of the Gambia River were 8 836 tonnes. Replacement of capture fisheries would lead to a net increase in carbon emissions, which would be highest for beef replacement (91 347 tonnes), followed by chicken production (5 692 tonnes), pork production (422 tonnes), farmed tilapia production (361 tonnes) and rice replacement (234 tonnes).

5.5 FISHERIES MANAGEMENT

National management strategies

In Senegal, fisheries have been governed by Law No. 67, 1970, which includes a code of conduct. However, these laws are being reviewed. Currently in Senegal, the Strategy for Sustainable Development of Fisheries and Aquaculture, 2001, which grants powers to introduce fishing rights, governs fisheries policy.

In Gambia, fisheries management is governed under the Fisheries Act, 2007; regulations under the act are standard control of access to the fishery through licensing, closed and open seasons for conservation areas and gear restrictions (The Gambia, 2007).

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6 NILE RIVER

6.1 OVERVIEW

The Nile is the world's longest river, spanning a length of 6 695 km and encompassing some of the territories of 12 countries. The true source of the Nile is controversial, with literature stating both the upper branches of the Kagera River in Rwanda (Hamza, 2014) and the Ruvyironza River in Burundi as the most remote sources of the Nile (NBI, 2012). The Nile is formed by three principal systems: the Blue Nile, the Atbara River and the White Nile. The catchments of the Blue Nile and Atbara River contribute between 85 percent and 90 percent of the annual Nile flow, with the White Nile and its extensive wetlands contributing between 10 percent and 15 percent (NBI, 2012). From the Ruvyironza River, the Nile River flows through Lake Victoria, Lake Kyoga and Lake Albert. From Lake Albert the river is known as the Albert Nile. In South Sudan, the river is known as the Bahr el-Jebel and flows through the Sudd Swamps and joins the Sobat River to form the White Nile (NBI, 2012). The White Nile meets the Blue Nile, which has its source in Lake Tana in Ethiopia (Hamza, 2014), at Khartoum and is joined by the Atbara River and forms the main Nile River. The Nile River then flows through Lake Nasser, a reservoir on the border of Sudan and Egypt, and eventually discharges into the Mediterranean Sea via its delta that splits into two branches, the Rosetta and Damietta (NBI, 2012; Hamza, 2014). The high evaporation rate within the Nile River Basin makes it vulnerable to drought events (NBI, 2012).

Table 6-1. Characteristics of the Nile River Basin

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
Sudan	1 340 133	43.73	34 923 800	26
South Sudan	637 014	20.72	12 144 084	20
Ethiopia	363 306	11.85	38 179 548	105
Egypt	248 901	8.12	8 644 524	350
Uganda	236 876	7.73	38 686 075	163
United Republic of Tanzania	119 754	3.91	11 376 625	95
Kenya	49 532	1.62	16 929 232	342
Eritrea	24 502	0.80	1 545 940	63
Rwanda	20 835	0.68	9 748 217	468
Democratic Republic of Congo	20 512	0.67	27 637 712	135
Burundi	13 194	0.43	6 108 018	463
Central African Republic	188	0.01	820	4
Total	**3 074 747**	**100**	**258 965 782**	**172**

Fish diversity

According to FishBase there are 154 species present in the Nile River Basin, of which 21 species are endemic. The most abundant families are Cyprinidae (32 species) and Mormyridae (22 species) (FishBase, 2017). In the Upper Nile there are 188 species including 16 endemic species. Lake Albert fauna comprise 46 species and 7 endemic species. The endemic species are *Lates macrophthalmus*, *Haplochromis loati* and *Thoracochromis* spp. The fish fauna of Lake Tana are relatively unknown, but 15 species of barbs have been identified in the lake. About 70 percent of the species are endemic, including 18 endemic cyprinids, 5 barb species and the Nile tilapia *O. niloticus* (Thieme and Brown, 2015).

Fish introductions

According to FishBase the Mozambique tilapia (*O. mossambicus*) is the only species that has been introduced to the basin (FishBase, 2017).

6.2 FISHERIES OVERVIEW

The fisheries in the Nile River, especially in the Nilotic lakes, make a major contribution to inland fish production in Africa (Witte *et al.,* 2009) and they have commercial, seasonal and subsistence attributes. In Egypt, inland fisheries operate on Lake Nasser, the Nile River's main channel, irrigation channels, the Nile Delta branches and the Northern Delta Lakes (Manzala, Burullis, Idko and Mariut) (Hamza, 2014). Nile fisheries in Egypt contribute 18.87 percent of the total production in Egypt, most coming from Lake Nasser (10 percent). The dominant species in the Egyptian Nile fisheries are tilapias (*O. niloticus, O. aureus, T. zilli* and *Sarotherodon galilaeus*) (31.6 percent), catfish (*C. gariepinus*) (20.27 percent), grass carp (*C. idellus*) (17.9 percent) and bagrid catfish (*Bagrus bajad*) (7.2 percent) (Samy-Kamal, 2015). The inland fisheries of Sudan are based on the Nile River system, contributing over 90 percent of the estimated production potential of the country. The Sudd Swamps, man-made reservoirs on the White Nile, Blue Nile, Abtara rivers and the main Nile River channel are the principal fishing locations. Commercially important species include Nile perch (*Lates niloticus*), bagrid catfish, silver catfish (*Bahruc docmac*), Nile tilapia, carp (*Labeo* spp.) and tigerfish (*Hydrocyon* spp.). Prior to 1986, fisheries in Ethiopia's Lake Tana were predominately for subsistence and were limited to the shoreline. The introduction of motorized boats to meet demand for fish from the capital Addis Ababa led to the creation of a professional industry, which had a negative impact on fish stocks. *O. niloticus* is the most targeted fish species, due to its high price and popularity amongst consumers, but *Labeobarbus* spp. and *C. gariepinus* are also common in markets (Witte *et al.,* 2009; Hamza, 2014). In Uganda, other than Lake Victoria, fish from the Nile Basin come from Lakes Albert, Edward and George, where commercial fisheries are established. In Lake Albert the fish markets are dominated by *Brycinus nurse*, (64 percent), *Neobola bredoi* (19 percent), *L. niloticus* (8 percent), *B. bayad* (4 percent) and *O. niloticus* (4 percent); fish markets have revealed changes in catch composition towards small-sized species (Witte *et al.,* 2009).

Fishing methods

Many fishing methods and techniques are used on the Nile River. In the Sudan the prevailing fishing techniques are hook and line, longlines, gillnets, seine nets, cast nets, traps and spear fishing (Witte *et al.,* 2009). A characteristic wetland fishery method is the use of traps that are set in submerged or emergent vegetation; one such trap is used to catch African lungfish (*Protopterus annectens*) (Hamza, 2014). Fisheries on the three East-African Lakes (Albert, George and Edward) use beach seines, cast nets and longlines (Gréboval, Bellemans and Fryd, 1994). In Egypt in 2012, there were 24 324 small sailing boats used in inland fisheries (GAFRD, 2012). The fishing gear used is mostly primitive, although trammel nets and longlines are used in some areas (Samy-Kamal, 2015), and on the delta lakes fishing gear mainly comprises seine nets, trammel nets and small bottom trawls (Feidi, 2003). In Lake Tana, the previous subsistence fishery used reed boats and locally made traps and gillnets to catch *O. niloticus*. Seasonal fishers on the lake used techniques such as barriers, basket traps, hooks, scoop nets and even poisoning of the shallow water areas (Nagelkerke and Sibbing, 1996). The development of the commercial motorized fishery introduced the use of more efficient nylon gillnets, with investment from the EU-sponsored Lake Fisheries Development Programme. However, by the end of the 1980s the motorized gillnet fishery began to decline, due to mechanical failure and lack of spare parts (Witte *et al.,* 2009).

Fish trade

In some countries of the Nile River Basin, data on the value and trade of fish caught are not known. In the Sudan, the total earnings from Nile fisheries in 2003 were USD 200 000 representing 0.4 percent of the national GDP (FAO, 2014). The growth of aquaculture in Egypt has led to a significant increase in the value of total fisheries production (aquaculture and capture fisheries), from USD 1.24 billion in 1999 to USD2.94 billion in 2012 (GAFRD, 1997–2012).

Employment

Table 6-2 indicates the estimated participation in Nile River Basin fisheries by country from the most recent information and may not fully represent the involvement in fisheries within the Nile River Basin.

Fisheries on Lake Nasser use 2 703 fishing vessels and 13 000 fishers. The number of boats has continued to increase, however the number of fishers peaked in 1975 and decreased to around 3 000 in 1981, but has since increased slowly. An estimated 4 000 fishers fish illegally in Egypt (van Zwieten *et al.,* 2011). Participation in fish-farming activities is higher than in capture fisheries in Egypt; an estimated 100 000 people are employed in the fish-farming sector (Dickson *et al.,* 2016). According to FAO, 5 079 people are also employed in the recreational fishing sector in Egypt (FAO, 2010).

Employment estimates from South Sudan indicate roughly 60 000 people involved in the fisheries sector; however, fisheries on the Sudd Swamps involve the use of 7 500 canoes and an estimated 151 000 people (Bailey, 1989). Due to political unrest and civil war, large parts of the country are still lawless which may affect the accuracy of the data (Linton and Mungule, 2012). In Ethiopia, subsistence fishery comprised 400 fishers; after the introduction of the motorized gillnet fishery, the fishery also had 130 inexperienced professional fishers operating from ten vessels (Witte *et al.,* 2009). In Lake Tana, the number of fishing boats had increased from 1 000 to 6 000 in 2012, which was linked to expansion in the Nile perch industry (NaFIRRI, 2012).

Table 6-2. Employment estimates for the Nile River Basin countries

Country	Fishing		Processing/trade		Total
	Men	Women	Men	Women	
Egypt	63 610	5 907	4 000	2 000	75 517
Sudan		28 300			28 300
South Sudan		13 000		50 000	63 000
Ethiopia	1 016	10	19 018	2 502	22 546
Burundi		5 236	503	1 174	6 913
Rwanda		5 499			5 499
Kenya		48 579	8 487	30 587	87 653*
United Republic of Tanzania	143 965	2 455			146 420*
Uganda	113 482	3 000			116 482*
Total	**434 059**		**118 271**		**552 330**

* Employment from Kenya, Uganda and United Republic of Tanzania from Lake Victoria.

Blank space indicates no data were available.

Sources: De Graaf and Garibaldi (2014); Linton and Mungule (2012); FAO (2014).

Estimated fisheries production

In all waterbodies in Egypt, tilapia form the largest portion of the catch (31 percent in Lake Nasser, 53 percent in Lake Burullus, 43 percent in Lake Manzala and 60 percent in Lake Mariout) (GAFRD, 2012). On the Nile River main channel, fisheries mainly target tilapia, catfish and grass carp, most of the catch being registered at landing sites in the delta regions such as Gharbia and Menouf. However, of the 695 registered landing sites on the Nile (Samy-Hamal, 2014), fish catches have only been reported from 21 landing sites on the Nile River and the lakes outlined in the General Authority for Fish Resources Development statistics yearbook (GAFRD, 2012). In addition, there are indications of underreporting of catches in Lake Nasser as van Zwieten *et al.* (2011) estimated that less than 50 percent of the actual catch is reported. Fishery statistics collected in Egypt are considered largely unreliable and uncomprehensive due to the sparsely distributed landing sites and countless number of unregistered landing sites (Hamza, 2014; Samy-Hamal, 2015). Therefore, fishery catches from the Egyptian Nile are likely underestimated.

Table 6-3 indicates the estimated fisheries production by country for the Nile River Basin countries, and by waterbody from various literature sources. When the fisheries of Lake Victoria are discounted, the fisheries on the Nile River in Egypt are the largest within the basin. Generally, fish catches from the lakes and wetlands of the Nile were higher than on the main channel.

Table 6-3. Fishery production estimates by country for the Nile River

Country	Catch estimate (tonnes)	Year	Reference
Egypt	349 553	2010	NBI (2012)
Uganda	374 300*		
United Republic of Tanzania	281 690*		
Kenya	120 432		
Sudan	57 000		
Burundi	17 000		
Ethiopia	16 770		
Rwanda	11 000		
Eritrea	52		
Democratic Republic of Congo	n/a		
Total	**1 227 797**		

*Most of the catch comes from Lake Victoria.

Table 6-4. Production estimates by waterbody for the Nile River

Country/waterbody		Catch estimate (tonnes)	Year	Reference
Egypt	Lake Nasser	26 290	2012	GAFRD (2012)
	Lake Burullus	52 076		
	Lake Manzala	62 272		
	Lake Mariout	7 427		
	Nile River main channel	66 623		
Sudan	Lake Nubia	1 000	2003	Witte *et al.* (2009)
	Gebel Aulia Reservoir	13 000		
	Senner Reservoir	1 000		
	Roseires Reservoir	1 500		
	White Nile Reservoir	13 000	n/a	Hamza (2014)
	Blue Nile Reservoir	1 500	n/a	
South Sudan	Sudd Swamps	30 000	2003	Witte *et al.* (2009)
Uganda	Lake Albert	110 000	2008	NaFIRRI (2012)
	Lake Kyoga	34 700	2006	Mbabazi *et al.* (2004)
	Lake Edward/George	6 000	1991	Coenen (1991)
Ethiopia	Lake Tana	292	2006	De Graaf *et al.* (2006)
Total		**426 680**		

Note: Lake Victoria is excluded as there is a separate profile for Lake Victoria.

In South Sudan most fish catches come from the Sudd Swamps with a catch of 30 000 tonnes in 2003, although the potential yield from the Sudd has been estimated at 75 000 tonnes/year. Therefore, the Sudd Swamps represent the only waterbody within the basin where there is room for expansion in fisheries (Witte *et al.,* 2009). Recent information on fisheries in the Sudan and South Sudan are scarce and figures are not representative of the full potential of fisheries, as civil war disturbances have had a negative impact on local fish production (Witte *et al.,* 2009; Hamza, 2014). Therefore, actual catch estimates are likely higher than those suggested in Table 6-4. Also, the fishing sector is constrained by inadequate roads, electricity supply and poor access to markets (Fisher and Cook, 2013).

Fish catches from Lake Albert were the highest from the East African Lakes, with most of the catch comprising *B. nurse*, the remainder being small (less than 5 cm total length) cyprinids such as *Neobola bredoi.* Catches of Nile perch amounted to 13 000 tonnes in 2008, or 12 percent of the overall catch and this was the most important sector by value (NaFIRRI, 2012). In comparison, fish catches from Lakes Edward and George were significantly less; however, Coenen (1991) estimated that catches from Lakes Edward and George could be raised by a factor of two or three due to illegal fishing.

Fishing has never been an important activity in Ethiopia, as fish is not highly valued as a source of cheap protein and is mainly eaten during religious fasting periods. The development of a commercial motorized gillnet fishery in Lake Tana was mainly to serve increased demand for fish from Addis Ababa. Catch composition is mainly made up of *O. niloticus* (50 percent), but the contribution of *C. gariepinus* and *Labeobarbus* spp. has halved; at present small fish (less than 10 cm) are not harvested. Fish catches in 2006 of 292 tonnes only came from the commercial fishery. Unfortunately, there are limited fisheries data available on seasonal and subsistence fisheries on the lake (Witte *et al.,* 2009).

Status of the fisheries: catch trends

In Egypt there was a decline in wild capture fisheries of about 22.8 percent between 1997 and 2012 (Samy-Hamal, 2015). Similarly, in other waterbodies in the Nile River Basin the general catch trend of *O. niloticus* has shown a steady decline. In Lake Nasser catches of *O. niloticus* declined from 35 000 tonnes in 2003 to 10 000 tonnes in 2012; catches of smaller miscellaneous fish increased from 2 800 tonnes in 2011 to 9 300 tonnes in 2012, an indicative sign of overfishing (GAFRD, 2012). Partly due to underreporting of catch data, some of the decline can also be attributed to the development of a large illicit market following the imposition of fixed price for fresh fish. Generally, catches decreased from 20 tonnes/boat/year in 1979 to 5 tonnes/boat/year in 2002 (Jul-Larsen *et al.,* 2003). Indications in Egypt are that the Nile perch populations have drastically declined; no catches of Nile perch have been reported in Lake Nasser and Lake Manzala since 2008 and no catches in Lake Burullus since 2009 (GAFRD, 2012).

In Lake Tana, the introduction of motorized commercial fisheries had a marked negative impact on fisheries in the lake, as catches fell to 255 tonnes from 360 tonnes in 1997. There was also a decline in the percentage composition of individual fish species in the catch; between 1993 and 2001, the proportion of *Labeobarbus* spp. in the catch declined by a third. By contrast, catches of Nile tilapia increased 50 percent by 2011, which is a reflection of the intense fishing pressure for *Labeobarbus* spp. (Hamza, 2014). After rapid decline in the motorized gillnet fishery in the 1990s, catch per unit effort (CPUE) remained relatively stable, but catches continued to decline. In 2003 a Dutch NGO donated five new fishing boats to the fishers of a small town on the shoreline. The consequent increase in fishing capacity is a likely cause for the increase in total landings of the gillnet fishery since 2003 (Witte *et al.,* 2009).

Catches in Lake Kyoga mainly consisted of dagaa (*Rastrineobola argentea*), after a collapse of the Nile perch fishery in the 1990s (Mbabazi *et al.,* 2004). The increase in catch of Nile perch from 700 tonnes to 71 000 tonnes caused a boom in fisheries in the 1970s, but by 1989 the Nile perch catch had decreased to around 15 000 tonnes/year (Ogutu-Ohwayo, 2004). The increase in Nile perch virtually decimated the haplochromine population of the lake, but the decline of Nile perch has led to some recovery in haplochromine populations (Mbabazi *et al.,* 2004). In Lake Albert, Nile perch gillnet fisheries catch dropped from 50 kg/boat/day to less than 20 kg/boat/day in 2008; the Nile perch longline fishery also experienced a similar drop in production, but is still considered the most important fishery on the lake (NaFIRRI, 2012).

Aquaculture

Estimated aquaculture production from the Nile Basin countries is outlined in Table 6-5. Due to the increasing human demand for aquatic products, aquaculture has gained considerable importance in Egypt. The Egyptian Government started to support fish farms financially in the late 1990s (FAO, 2010). Consequently, aquaculture production increased 475 percent between 1999 and 2012 (Samy-Hamal, 2015) and represented 74 percent of the fish production in Egypt (El-Sayed, Dickson and El-Naggar 2015). Egypt produces 93 percent of the combined aquaculture production of the Nile River Basin countries (NBI, 2012), and is the largest aquaculture producer in Africa accounting for 70.5 percent of aquaculture and 65 percent of the value (FAO, 2017). Farmed Nile tilapia production in Egypt produced 875 513 tonnes in 2015, far exceeding that of any other country within the basin (FAO, 2017). Aquaculture from all other countries within the basin is significantly underdeveloped in comparison; however, it is on the rise in Uganda, Kenya and United Republic of Tanzania mainly through expansion of fishing effort on Lake Victoria.

Table 6-5. Aquaculture production estimates by country for the Nile River Basin in 2010

Country	Catch estimate (tonnes)	Year	Reference
Egypt	539 747	2010	NBI (2012)
Uganda	4 002		
United Republic of Tanzania	4 102		
Kenya	26 700		
Sudan	2 000		
Burundi	2 002		
Total	**578 553**		

Recreational fishing

In addition to the artisanal fishery on Lake Nasser, it is also a major tourist destination for recreational anglers targeting *L. niloticus*, as the International Game Fish Association world record for *L. niloticus* of 104 kg was caught in Lake Nasser. In addition, popular target fish are tigerfish and catfish (Weyl and Cowley, 2016).

6.3 THREATS TO THE FISHERIES

Water quality

Generally, within the Nile River Basin there is lower water quality in the downstream basins compared with those located upstream; this results from continuous flow that dilutes pollutants and carries them downstream and the presence of less-industrialized countries upstream. In the mid-basin, contaminants from the Blue and White Nile accumulate in Lake Nasser, where water quality is affected by the continuous fluctuation of its water level (Hamza, 2014). The Nile Delta is the most polluted area of the river with the lowest water quality, ranging from eutrophic to hypertrophic conditions (Hamza, 1999). This section of the river suffers from accumulation of pollutants from upstream, as well as effluent from agriculture and industry, which are a leading cause of declines in fisheries. High concentrations of heavy metals in sediment lakes within the delta may cause contamination in fish (Barakat, 2004).

Habitat modification

Completion of many large reservoirs has changed the flood regime of the river and many lagoons have become permanently isolated. The surface area of the lakes (Mariut, Edku, Burullus and Manzala) in the delta has been reduced by as much as 50 percent since the 1950s. The lakes have been reduced for highway construction and reclamation of land for agriculture, which have led to a change in the lakes' ecosystems (Hamza, 2014). Similarly, redirection of water away from the Sudd Swamps for human activities has resulted in ecosystem changes and the formation of isolated ponds that have promoted the growth of weeds, which has negatively influenced the fisheries in the region (Hamza, 2014). In Egypt, the impoundment of the Nile River by the Aswan Dam to create Lake Nasser led to increased fish yields in the impounded section of the river. However, this is not the case for all impoundments within the river basin (Marmulla, 2001). Construction of the Zifta and Faraskour dams on the Damietta channel has led to reduction in species diversity, where now only four species occur, and deep summer pools and spawning grounds that formed refuges for fish have now been lost (Ishak, 1981).

Overfishing

Almost 90 percent of the fish produced within the Nile region originates from freshwater sources, with only 10 percent coming from the vast marine areas controlled by the basin states. Consequently, most of the inland fisheries now show signs of being overfished (NBI, 2012). For instance, the fishery on Lake Albert is heavily exploited and illegal fishing is endemic. Access to fisheries on Lake Albert is unrestricted; although fishers are required to register, the number of licences is not limited. Given the lack of alternative livelihood options, fishing is considered an attractive source of employment, as it is not difficult to enter fisheries and illegal gear (cast nets and monofilament nets) are cheap to purchase. In the past, lakeshore individuals could rely on fishing for their livelihoods, therefore fishers have not diversified and remain dependent on fishing. As fishing is no longer a reliable source of income anymore, fishers engage in illegal activities such as fishing on breeding grounds or using gear that results in overfishing and catching of immature fish, simply to guarantee fish catch. Also, theft of gillnets is widespread so fishers try to minimize losses by using cheaper smaller meshed nets or by using more destructive methods of fishing (NaFIRRI, 2012). Overfishing is also observed in Lake Nasser where catches have declined by about 80 percent since 1981, and, as is consistent with many other waterbodies within the Nile River Basin, much illegal fishing and catches goes unreported. In this context the exploitation rate of fisheries is relatively unknown (Azzazay, 2015).

Climate change

Over the entire basin average annual temperature for the period 2070 to 2099 will increase between 3.6 °C and 4.4 °C relative to historical (1950–1999) average annual temperatures. Generally, precipitation will increase during the early twenty-first century and river flow will increase, but the effects of temperature increases later in the twenty-first century will lead to precipitation decreases and reduced stream flow. Declines in rainfall are likely to be more severe in the southwestern region of the basin by as much as 40 percent; in contrast tropical regions will experience an increase of 7 percent (IPCC, 2007). Changes in rainfall of between -16 percent and +40 percent in the early twenty-first century (2010–2039) could result in stream flow changes of between -39 percent and +12 percent (Beyene, Lettenmaier and Kabat 2010). The Nile River Basin is particularly vulnerable to the impacts of global warming due to the fragility of its natural ecosystems and dominance of poor and rural people in upstream countries who are heavily dependent on sectors such as fishing and agriculture that are highly sensitive to climate change (NBI, 2012).

6.4 EQUIVALENT FOOD REPLACEMENT

The vulnerability of the Nile River Basin to climate variability makes the basin and its inhabitants susceptible to crop failure, thus some of the occupants of the basin are considered food insecure (NBI, 2012). Fishing in the Nile Basin not only provides employment and income but also provides a source of accessible and affordable animal protein, especially in poor countries.

Given the importance of fisheries within the basin, food replacement estimates were estimated on a 50 percent loss to capture fisheries from waterbodies from the Nile Basin (Table 6-5). These figures do not include the catch from Lake Victoria which has its own profile; as such United Republic of Tanzania and Kenya are not included in the replacement discussion. Food replacement sources consist of livestock, (beef, pork and chicken), aquaculture (tilapia) and crops (cassava and maize).

Table 6-6. Food production (tonnes), water (km³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Tilapia	126 216 (13.4)	0.4 (0.4)	5 737 (0.2)	0.03
Beef	132 458 (8.0)	2.0 (2.0)	15 283 (1.4)	8.29
Pork	69 274 (49.9)	0.4 (0.4)	9 446 (0.9)	0.03
Chicken	218 166 (18.1)	0.9 (0.9)	5 854 (0.5)	0.51
Maize	280 318 (1.5)	0.3 (0.3)	500 (0.1)	0.01
Cassava	158 289 (1.9)	0.3 (0.3)	140 (0.04)	

Energy replacement (Table 6-6)

Cassava production would require production, equivalent to 1.9 percent of current production (2014 production was 8.4 million tonnes). However, according to FAO (2017), Eritrea, Egypt, Ethiopia and the Sudan reported no production of cassava in 2015, which may indicate unsuitability for cassava production in these countries. But increasing climate variability within the basin could limit any expansion in agriculture. Farmed tilapia and beef production would require similar replacement estimates, equivalent to 13.4 percent and 8.1 percent of current production, respectively. However, tilapia aquaculture in Egypt represents 93 percent of the total tilapia aquaculture within the Nile Basin; fish farming in other countries is underdeveloped. When aquaculture production from Egypt is removed, the replacement value is equivalent to 193 percent of current production from the other basin countries (farmed tilapia production within the basin countries in 2015 was 940 972 tonnes, of which 875 513 tonnes came from Egypt).

Water demand (Table 6-6)

Replacement of fisheries with beef would have the largest impact on freshwater resources, with water demand equivalent to 2.0 percent of agricultural water withdrawals from the riparian countries (agricultural water use was 104 km^3 in 2000-2010). Farmed tilapia, pork, maize and cassava replacement all require a similar water demand, equivalent to 0.3 percent to 0.4 percent of current agricultural water use. Climate change within the basin could affect agricultural water use, as the prospect of water scarcity becomes a growing concern; reduced precipitation, water flow and increased evapotranspiration could reduce the available water for agricultural production in the future.

Land requirements (Table 6-6)

Replacement of capture fisheries with farmed tilapia production would require 5 737 km^2, equivalent to 0.2 percent of the Nile River Basin area. In the absence of capture fisheries, aquaculture production could expand within existing waterways; the development of more efficient farming techniques could also reduce the amount of land needed for fish farming. Chicken production would require the smallest land change from an animal protein source, equivalent to 0.5 percent of pastureland in the basin. Climate changes poses the problem of an increasingly arid environment, which would be unsuitable for crop production and result in insufficient food for livestock production.

Greenhouse gas emissions (Table 6-6)

Carbon emissions from 50 percent of capture fisheries from the Nile River Basin were estimated at 802 158 tonnes. Net increases in carbon emissions from the replacement of fisheries with other food sources would be greatest with replacement with beef (8.29 million tonnes), followed by chicken (0.51 million tonnes), pork (0.03 million tonnes) farmed tilapia (0.03 million tonnes) and maize (11 154 tonnes).

6.5 FISHERIES MANAGEMENT

National management strategies

In Egypt, despite vigorous national legislation to address fishery-related issues, weak enforcement, low compliance and unregulated fishing suggest a need for the restructuring of fisheries management. The Law 124 of 1983 provides the General Authority for Fish Resources Development with the responsibility for development and management of fishery resources. This includes issuing fish licences, collecting fishery statistical data and supervising fishery cooperatives. All fishing vessels are required to have a fishing licence, which indicates the type of gear used and the permitted fishing ground. It is illegal to use destructive, poisonous or illegal fishing practices. Wild fisheries of Egypt are considered underregulated with no clear management and future fisheries management is aimed at improving current management (Samy-Kamal, 2015). In Lake Nasser, the Lake Nasser Development Authority (LNDA) is responsible for managing and developing reservoir fisheries. This is achieved through a one-month closed season during peak *O. niloticus* spawning; gear restrictions, allowable market sizes and stock enhancement are also carried out by the LNDA (van Zwieten *et al.,* 2011).

In the Sudan, the Freshwater Fisheries Act, 1954 serves as an outdated platform for fisheries management. Management measures address permitted and illegal fishing methods, restricted access to certain fishing areas and licence systems for fishing vessels and fishers (FAO, 1954).

In Kenya, fisheries management is under legislation in the Fisheries Protection Act, 2012. Management measures consist of controlling access to fisheries, regulation of gear use, regulation of the landing of fish, issuing fishing licences and registration of fishing vessels and permitted fishing methods (Laws of Kenya, 2012).

Transboundary management

On a transboundary level, the Nile Basin Initiative (NBI) is the most important platform for cooperative action and management within the basin. The NBI is working to implement the Shared Vision Programme which comprises eight projects, such as the Nile Basin Transboundary Environmental Action Project to promote cooperation among Nile Basin countries in protecting and managing the environment and the Nile River ecosystem. Transboundary water policy within the basin recognizes that future development of the basin must be environmentally sustainable. The NBI policy guidelines aim to develop water resources in a sustainable and equitable way; to ensure efficient and optimal use of water for resources; target poverty eradication; and promote economic integration (Timmerman, 2005). The NBI Wetland Management Strategy aims to foster the sustainable management and utilization of the basin wetlands; this involves the recognition of the importance of the wetlands as an area of high biodiversity and water storage and purification. As part of the management strategy, compiling information and knowledge on Nile Basin wetlands' functions and services and their contribution for socio-economic development will be undertaken. This should recognize the importance of fisheries within these wetlands for sustaining livelihoods (NBI, 2013).

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7 LAKE TURKANA

7.1 OVERVIEW

Lake Turkana is the largest lake in the eastern arm of the Great Rift Valley and the fourth largest by volume in Africa (237 km^3). The lake has a mean and maximum depth of 31 m and 115 m, respectively. The lake has three volcanic islands, the north, central and south islands (SDOF, 2013). The salinity of Lake Turkana is higher than that of any other of the African Rift Lakes; this is due to volcanic activity within the catchment. The lake is situated primarily in northwest Kenya, with only the northernmost end, the Omo Delta, in Ethiopia (SNV, 2005) (Table 7-1). The lake has no surface outlet and receives water from 12 tributaries, but the Omo River (which originates in the Ethiopian Massif) supplies over 90 percent of the lake's inflow (Beadle, 1981). Strong prevailing southeasterly winds are a predominant feature of the area, which creates surface currents which generate upwelling conditions on the eastern shore. As such, the lake is well mixed, with oxygen and temperature regimes showing little or no stratification (Hopson, 1982).

Table 7-1. Characteristics of Lake Turkana

Country	Area of the lake (km^2)	Percent area of the lake in countries	Population of the lake basin
Kenya	97.16	1.3	
Ethiopia	7 376.84	98.7	300 000
Total	**7 474**	**100**	

Fish diversity

According to FishBase there are 65 species in Lake Turkana, the most abundant family being Cyprinidae (16 species). The species composition consists of 11 endemic species, including the Turkana jewel cichlid (*Hemichromis exsul*), Lake Turkana barb (*Enteromius turkanae*), Lake Rudolf lates (*Lates longispinis*), Omo lamprey (*Lacustricola jeanneli*) and Lake Rudolf lamprey (*Micropanchax rudolfianus*) (FishBase, 2017).

Fish introductions

According to FishBase there has only been one documented introduction to Lake Turkana, which was the redbelly tilapia (*Coptodon zilllii*) (FishBase, 2017).

7.2 FISHERIES OVERVIEW

There are 12 commercially important species that are fished on Lake Turkana. These can be separated into four categories: the tilapias fishery in the littoral zone, which is dominated by *Oreochromis niloticus*, and is the most targeted fishery; the inshore demersal fishery, which is dominated by *Labeo horie*; the offshore demersal fishery, which is dominated by *Bagrus bayad*; and the pelagic fishery which consists of tigerfish (*Hydrochnus forskalii*), *Alestes baremose*, *Alestes minutus*, Nile perch (*Lates niloticus*) and the catfish (*Synodonis schaal*) (SNV, 2005). Most of the fishing activity around the lake takes place in shallow lagoons and the Ferguson's Gulf area of the lake (Kolding, 1989). The fishing communities of the lake consist of several tribes, of which the Turkana tribe located along the western shores of the lake predominates. The northern waters of the lake are the richest fishing grounds; as most fish species migrate there to spawn, most commercial fishers in the lake strive to operate there. The lack of clear territory boundaries is a source of conflict between the tribes, who are known to attack one another (SNV, 2005). The fishery is characterized by boom-and-bust cycles in fish landings associated with fluctuations in the lake level, especially the filling up and drying out of Ferguson's Gulf. The filling up of the gulf is associated with a boom in fisheries catches (SDOF, 2013).

Fishing methods

Fishing activities mainly take place in a few areas along the lake, particularly in shallow lagoons and Ferguson's Gulf where beach seining is the predominant fishing method. The other main types of fishing gear used in Lake Turkana are set nets, beach seines, longlines (hook and line, 2 km to 10 km long) and gillnets (usually 3-inch mesh sizes). Longlines are mainly used to target species such as Nile perch, catfish, tigerfish and *Bagrus spp*. (SNV, 2005).

Fish trade

Fish production from the lake in 2013 had an ex-vessel value of USD 4 243 561), an increase on the 2012 catch, which was valued at USD 2 973 613) (SDOF, 2013). There are no lake wide socio-economic studies for Lake Turkana and there are no official landing sites. Fish catches are landed all along the lake and at these sites fishers usually tether large fish such as Nile perch to anchors. This innovative method helps to keep the fish alive and fresh as there is no ice-making infrastructure around the lake. About 5 percent of the total landings is traded as fresh and around 80 percent of all fish traded is sun-dried. The lack of a strong fish-eating culture amongst the riparian communities, lack of ice-making facilities, hot ambient temperatures and long distances between capture sites and market centres are factors that constrain the development of fishery infrastructure (SNV, 2005).

Employment

There has never been a frame survey for Lake Turkana, so the number of fishers is unknown. The number of fishers fluctuates depending on whether Ferguson's Gulf is full or empty (SNV, 2005). Recent estimates from the State Department of Fisheries states that the lake communities rely entirely on fishing and that fishing directly supports around 7 000 fishers and 6 500 fish traders and transporters (SDOF, 2013). It is very common to see women participating in fishing activities, casting and pulling nets, unlike in many other regional lakes. Also, artisanal fishing is usually carried out by family units (SNV, 2005).

Estimated fisheries production

Estimated fisheries production from Lake Turkana is outlined in Table 7-2. Fisheries production from the Kenyan portion of the lake in 2013 was 4 338 tonnes, which was an increase of 44.6 percent compared to 2012 when the production value was 3 001 tonnes. Catch trends from Lake Turkana are linked to the lake's water level and as such are susceptible to fluctuations and have been considered unpredictable for some time. Apart from the increase in production from 2012 to 2013 there has been a continuous decline in catches since 2009 (SDOF, 2013). Tilapias dominated the catch in 2013 (41.8 percent), but together with *Labeo horie, Lates niloticus, Alestes* and *Distichodus niloticus,* these five species constituted 85.5 percent of the total catch from the lake (SDOF, 2013).

Fishery data collection around Lake Turkana is challenging due to the remoteness of the main fishing areas and expansiveness of the shoreline. Near comprehensive data was collected in some parts of the lake during two short periods of monitoring (1972–1975 and 1988), but most fisheries data are based on fishing activities on the western side of the lake. Insecurity in some parts of the lake, particularly in the north, means that data collection in these areas is difficult. Fisheries data from the eastern side of the lake are not reported, particularly if fish is consumed locally or goes through non-traditional marketing paths. In Kenya, most data are for dried fish, as reported by fish traders, therefore equivalent weights for fresh fish must be established. Also, as not all the fish is dried and some fish may spoil before it is sold (SNV, 2005), fisheries data are only indicative of the potential production. Kolding (1989) stated that landing statistics from Lake Turkana were considered a serious problem and the official statistics were subject to repeated criticism regarding their accuracy and reliability (Kolding, 1989).

This could indicate that the data in Table 7-2 may not be an actual representation of the amount of fish caught. Also, a large portion of the data which is not recorded is conducted within the Ethiopian portion of the lake. SNV (2005) described fisheries in this region as increasing in sophistication in targeting large pelagic species like Nile perch, destined for export to Europe. Therefore, the figures in Table 7-2 for fishery production in Ethiopia are likely an underestimation of current production.

Table 7-2. Estimated fisheries production for Lake Turkana

Country	Catch estimate (tonnes)	Year	Reference
Kenya	4 338	2013	SDOF (2013)
Ethiopia	75	n/a	Janko (2014)
Total	**4 413**		

Status of the fisheries: catch trends

Historical data have shown continuous periods of boom and bust within the fishery. For instance, peak fishery production in 1998, 2004 and 2009 was approximately 9 000 tonnes to 11 000 tonnes. A steep drop in production of about 75 percent characterized the following year after a boom in fishery production. Between 1990 and 1995 the Lake Turkana fishery catch suffered a large decline in production (under 1 000 tonnes per year).

Aquaculture

Lake Turkana offers potential for cage culture, with good water quality and water temperature, but the remoteness of the lake slows the development of cage culture (Halwart, Soto and Arthur, 2007). Previously, a pond aquaculture farm was constructed by the Kenyan Department of Fisheries on the western side of the lake. However, this operation failed, as the ponds developed excessive salinity due to the high evaporation rates in the region leading to dwarfed development of cultured tilapia (SNV, 2005).

Recreational fishing

Due to the remoteness of Lake Turkana, the lake does not attract as many sport fishers as other freshwater lakes in the region. Fishing is conducted with rod and line and the most targeted species are Nile perch, tigerfish, tilapia, *Alestes*, yellowfish and barbell (Iolaus, 2017).

7.3 THREATS TO THE FISHERIES

Climate change

The last several decades of data from Kenya have shown that air temperature increased between 2 °C and 3 °C between 1967 and 2012. Rainfall patterns have also changed and the rainy season has shortened. The basin has often experienced periods of cyclical droughts but increasing temperatures and shifting precipitation patterns threaten to reduce the water supply and inflow into the lake. Some believe that Lake Turkana could recede into two small pools. Reduced water levels into the lake will have a damaging impact on the environment and livelihoods of people around Lake Turkana. Reduction in inflow from the Omo River will increase the salinity level of the lake and raise water temperature, which will increase the rate of evaporation, potentially threatening fish populations (Lokoel, 2014).

Habitat modification

The fisheries and livelihoods of the communities that depend on the Lake Turkana fisheries are under severe threat from the construction of the Gibe 3 Dam on the Omo River in Ethiopia. Completed in 2016 the dam has put an end to the river's natural floods; in 2015 there was no artificial flood release and in 2016 the flood was too low to sustain crop production. The dam blocked the southwestern part of the Omo River, which runs for 760 km into Lake Turkana (Survival International, 2017). Water level drops of between 13 m and 22 m, from reduced inflow from the Omo River, are predicted to reduce the lake volume by 42 percent to 59 percent (Lokoel, 2014). This will decimate the fisheries of the lake. The reduction in natural floods will diminish the cue for breeding and migration and increased salinity will lead to dwarfed fish growth (Lokoel, 2014). An Environmental and Social Impact Assessment (ESIA) was only approved in 2008, a full two years after construction of the dam had begun. Also, the ESIA was carried out by an Italian company funded by the Ethiopian Electric Power Corporation, which raised questions over its credibility. The ESIA was in favour of the project and even stated that the environmental impacts on tribes would be negligible and even positive (Survival International, 2017).

7.4 EQUIVALENT FOOD REPLACEMENT

Fisheries are hugely important to the Lake Turkana communities whose livelihoods are wholly dependent on the sector and, because of the aridity of the environment, alternative livelihood options are not available. Equivalent food replacements were established for a 50 percent loss in fisheries production from Table 7-2. Given the small size of the area of the lake in Ethiopia and lack of a fish-eating culture there, replacement estimates focus on the impact of replacement of fisheries in Kenya (replacement figures will only use the production estimate from Kenya). Replacement food sources consist of aquaculture (tilapia), livestock (beef, pork and chicken) and maize.

Table 7-3. Food production (tonnes), water (million m³), land (km²) and net increase in carbon emissions (thousand tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (thousand tonnes)
Tilapia	1 283 (9.2)	3.84 (0.2)	58 (0.8)	0.34
Beef	1 346 (0.3)	20.76 (1.1)	155 (0.7)	84.31
Pork	704 (3.9)	4.21 (0.2)	96 (0.5)	0.39
Chicken	2 218 (8.6)	9.59 (0.5)	52 (0.3)	5.25
Maize	2 849(0.08)	3.48 (0.2)	5 (0.009)	0.11

Energy replacement (Table 7-3)

In 2015, replacement of 50 percent of capture fisheries from Lake Turkana with farmed tilapia production would require the equivalent to 9.2 percent of tilapia production (2015 production was 13 991 tonnes). Pork production would require the smallest amount to replace fisheries, equivalent to 3.9 percent of production in 2014 (2014 production was 25 772 tonnes). Maize production would require the largest increase in production, but as maize is a staple crop in Kenya production levels are high, and as such compared to current production the replacement estimate is small (0.08 percent of 3.6 million tonnes of maize produced in 2014).

Water demand (Table 7-3)

Replacement of capture fisheries with beef production would have a large impact on water resources, equivalent to 1.1 percent of agricultural water use in Kenya (1.9 km³ in 2010). The remaining replacement food items would require similar replacement water demand, equivalent to 0.2 percent to 0.5 percent of agricultural water use in Kenya. These values may not be realistic, given the remoteness of the basin, increasing aridity of the environment and salinity of the lake, which is unsuitable for consumption.

Land requirements (Table 7-3)

Farmed tilapia production would require land increase, equivalent to 0.8 percent of the Lake Turkana area within Kenya. As aquaculture on the lake is non-existent, the creation of aquaculture practices on the lake could substantially increase food production in the area. Beef would require the largest land conversion, equivalent to 0.7 percent of the pastureland area in Kenya (the pastureland area in 2014 was

21 300 km^2). Chicken production would require the smallest increase in land conversion, equivalent to 0.3 percent of the pastureland in Kenya.

Greenhouse gas emissions (Table 7-3)

Estimated carbon emissions from a 50 percent loss to capture fisheries in Lake Turkana were 8 155 tonnes. Net increases in emissions from replacement of capture fisheries would be lowest with maize replacement (113 tonnes). Beef production would have the largest replacement value (84 312 tonnes), followed by chicken (5 253 tonnes), pork (389 tonnes) and farmed tilapia (333 tonnes).

7.5 FISHERIES MANAGEMENT

The Department of Fisheries (DOF) is the governmental department mandated with the management of the Lake Turkana fisheries. In accordance with the Fisheries Act, 1991 the DoF is responsible for licensing fishers and fish traders, controlling mesh sizes, restricting access to the fishery and issuing of closed seasons (SNV, 2005). The DoF has an office on Lake Turkana, but it is only staffed by 18 people and as such the department lacks physical presence in most parts of the lake, which further limits the department's ability to collect data on enforced regulations.

The Kenya Wildlife Services (KWS) is responsible for the management of marine parks in Lake Turkana, of which there are three which serve as important ecological areas. The KWS restricts fishing access to these national parks and controls access (SNV, 2005).

There is an urgent need to develop a management plan specific for Lake Turkana fisheries. Given the central role that the DoF would play in developing Lake Turkana fisheries, it is important that the existing institution be strengthened and community participation also be strengthened. This would be enabled by capacity development of beach management units, training fishers on hygiene and sanitation, fish handling, processing and fish value addition, as well as funding for provision of facilities to boost infrastructure and equipment (SDOF, 2013).

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8 LAKE VICTORIA

8.1 OVERVIEW

Lake Victoria is the largest tropical lake and the second largest freshwater lake in the world. It has a shoreline of 3 440 km, but is shallow (84 m maximum depth) with a volume of 2 760 km^3, water residence time of 23 years and a catchment area of 195 000 km^2. The lakeshore is shared by Kenya, Uganda and United Republic of Tanzania (Table 8-1) and its catchment extends to Rwanda and Burundi. The lake has seven primary river inflows (the Kagera, Katonga, Sio, Yala, Nyando, Sondu Miriu and Mara rivers) and the outflow flows into the Nile River. Most of the water input is through rainfall (117 km^3/year), followed by basin discharge (26 km^3/year) and the output is mainly through evaporation (105 km^3/year) followed by outflow via the Nile River (33 km^3/year).

Table 8-1. Characteristics of Lake Victoria

Country	Area of the lake (km^2)	Percent area of the lake in countries	Population of the lake
United Republic of Tanzania	35 088	51	
Uganda	29 584	43	
Kenya	4 128	6	
Total	**68 800**	**100**	**25 000 000**

Fish diversity

The estimated fish diversity of Lake Victoria is generally high. According to FishBase there are 255 species in Lake Victoria of which 117 are endemic and the most abundant family is Cichlidae (170 species) of which 59 percent is endemic (FishBase, 2017). Lake Victoria previously contained up to 400 species, but in the 1970s, an estimated 150 to 200 native haplochromines became extinct, in part due to the introduction of the Nile perch, but also through fishing pressure and environmental change (van Zwieten *et al.,* 2016): an event described as one of the largest vertebrate extinction events of recent times (Kaufman, 1992).

Fish introductions

FishBase has indicated that there are ten introduced species in Lake Victoria, which consist of European eel (*Anguilla anguilla*), smallmouth bass (*Micropterus dolomieu*), largemouth black bass (*Micropterus salmoides*), redbreast tilapia (*Coptodon rendalli*), redbelly tilapia (*Coptodon zillii*), Nile tilapia (*Oreochromis niloticus*), *Oreochromis leucostictus*, Nile perch (*Lates niloticus*), eastern mosquitofish (*Gambusia holbrooki*) and guppy (*Poecilia reticulata*) (FishBase, 2017). Introduced Nile perch (*Lates niloticus*) and Nile tilapia (*Oreochromis niloticus*) constitute a major part of the fish yield (Kolding *et al.,* 2014).

8.2 FISHERIES OVERVIEW

Lake Victoria supports one of the world's largest inland fisheries aimed at both domestic consumption and international export. The lake originally supported a multispecies fishery, in which two tilapiine species (*O. esculentus* and *O. variabilis*) were the most important. In order to convert the native haplochromine fishes into more valuable biomass, Nile perch was introduced in the 1960s. Lake Victoria now supports a valuable artisanal and commercial fishery (Abila, 2003; Cowx, 2005). The artisanal fishery developed rapidly in terms of technical efficiency after the introduction of the Nile perch with the establishment of synthetic gillnets and outboard motors leading to a substantial increase in fishing effort (Kudhongania and Chitamweba, 1995). Nile perch catch grew rapidly from 13 000 tonnes in 1975 to 567 268 tonnes in 2006 (Geheb *et al.,* 2008) although the dagaa (*Rastrineobola argentea*) fishery is the largest fishery on the lake by weight (Kolding *et al.,* 2014). Lake Victoria's fishery has declined significantly and is now based on three species consisting of Nile perch, dagaa (both 42 percent in terms of volume) and Nile tilapia (15 percent) (Kolding *et al.,* 2014).

Fishing methods

The most common fishing gear on the African Lakes is gillnets, longlines, hand lines and seine nets. On Lake Victoria the use of specialist dagaa seine nets increased from 3 588 in 2000 to 15 064 in 2012 (LVFO, 2012). Gillnets and longline hooks are predominately used for catching Nile perch, and hand lines and fish traps are mainly used to catch tilapias (Abila, 2003). Illegal gear use is rife, with beach seine nets, monofilament nets and reduced mesh-size nets being widely used. In 2010, there were 64 595 fishing boats on Lake Victoria, of these, most (62 percent), were paddleboats (LVFO, 2017).

Fish trade

The Nile perch boom coincided with an emerging European market for high-quality white fish meat that promoted the development of industrial fish-processing capacity along the lake's shoreline (Harris *et al.,* 1995). The export of Nile perch has since expanded away from the European Union (EU) to the Near East, the United States and Australia, and makes up a substantial portion of foreign exchange earnings to the littoral states of Lake Victoria. The Lake Victoria fishery contributes from 2 percent to 3 percent to the GDP of Kenya, Uganda and United Republic of Tanzania (Yongo, Keizire and Mbilinyi 2005) and fish catch value combined with the value added through processing and marketing of the Lake Victoria fishery is valued at USD 600 million (LVFO, 2007).

Employment

Lake Victoria provides direct employment for 208 013 fishers (50 percent from United Republic of Tanzania, 19 percent from Kenya and 31 percent from Uganda) (Ministry of Livestock and Fisheries Development & Department of Fisheries Development, 2015) but along the value chain around 4 million people are supported by the Lake Victoria fishery. Participation of women in Lake Victoria fisheries is generally low, however, 1 471 fishing vessels in Kenya were owned by women in 2015 (Ministry of Agriculture, Livestock and Fisheries, 2015). The typical view is that women are excluded from the fishery as they find it too risky or strenuous. More realistically, men have secured traditional gender-defined roles to exclude women as a source of potential competition (Madanda, 2003). Previously, women dominated the Nile perch processing sector, but as most of the Nile perch catch goes to processing factories, women have turned to processing Nile perch rejected by the factories to sustain their livelihoods (Abila, 2003).

Estimated fisheries production

Lake Victoria is one of the world's largest freshwater fisheries. Variability in fish catches reflects the dynamic state of the fish stocks, thought to be the result of fluctuations in the dagaa fishery (Kolding and van Zwieten, 2011). Table 8-2 indicates the estimated catch for each of the riparian countries. Basin-wide estimates from the Lake Victoria Fisheries Organisation (LVFO) were considerably higher than fishery estimates from the riparian countries (Table 8-2). The LVFO estimated fish catch of 1 061 107 tonnes in 2016, of which Nile perch made up 24 percent (254 665 tonnes), dagaa 54 percent (572 997 tonnes), tilapia 7 percent (74 277 tonnes), haplochromines 13 percent (137 943 tonnes) and other species less than 1 percent (10 611 tonnes) (LVFO, 2017).

These figures call into question the quality of national statistics reported to FAO, as catch estimates by the LVFO of 1.1 million tonnes in 2016 are significantly more than the 838 649 tonnes reported to FAO by each riparian state from all inland waters in the same year. However, data collection, particularly in Uganda and United Republic of Tanzania, is not conducted due to lack of funds and staff. Catch recording at landing sites is either non-existent or the data produced are unreliable; generally, the lack of financial resources and low motivation of beach staff instil little confidence in the catch statistics. In Uganda, there are large discrepancies between the catches of Nile perch reported by the LVFO and the Ugandan

Government (Welcomme and Lymer, 2012). Also, the LVFO conducts its own separate lake-wide surveys, which may also explain these differences.

Table 8-2. Estimated fisheries production for Lake Victoria

Country	Catch estimate (tonnes)	Year	Reference
Whole lake system	1 061 107	2016	LVFO (2017)
United Republic of Tanzania	231 000	1990	Cowx *et al.* (2003)
Kenya	220 000	1992	
Uganda	175 000	2000	
Total	**1 061 107**		

Note: Total production only includes the whole lake system.

Status of the fisheries: catch trends

In Kenya, fish landings increased from around 19 000 tonnes in 1997 to approximately 220 000 tonnes in 1992. In Uganda fishery yields increased from 11 000 tonnes in 1977 to 175 000 tonnes in 2000. In United Republic of Tanzania fishery yields increased from 72 000 tonnes in 1983 to 231 000 tonnes in 1990. All of these statistics are attributed to increases in Nile perch production (Matsuishi *et al.,* 2006). The annual catch rate prior to Nile perch introduction was around 2.3 tonnes/fisher, increasing rapidly to a high of 10.5 tonnes/fisher in 1990 and declining again to 4.9 tonnes/fisher in 2005 (Matsuishi *et al.,* 2006). Lake Victoria fisheries have, however, shown a decline in Nile perch catch and a shift in species composition from higher trophic species to lower-level trophic species (Matsuishi *et al.,* 2006). By 2015, the catch had declined to 752 024 tonnes (Nile perch, 165 083 tonnes; dagaa, 566 570 tonnes; tilapia, 20 370 tonnes).

Aquaculture

Aquaculture is a relatively new venture on Lake Victoria, introduced by the Kenyan Government in 2009 to boost fisheries production and to eradicate poverty and hunger. Cage culture practices are being used to reduce hunting pressure on wild capture fisheries. Presently, Nile tilapia (*O. niloticus*) is the only fish species raised in cages, but the aim is to expand cage culture activities to rear Nile perch. Cage farming is prohibited by law on the Tanzanian side of Lake Victoria for fear of environmental pollution (Kashindye *et al.,* 2015). Due to the small scale of aquaculture activities at present there are no real indications of production estimates.

Recreational fisheries

Lake Victoria offers recreational fisheries with many species found near the shoreline. The large size of Nile perch makes it attractive as a sport fish. Repeated covert introductions of Nile perch by the Uganda Game and Fisheries Department were part of an effort to improve sport fishing and improve the overall fishery (Pringle, 2005). No estimates of the number of recreational fishers or the quantity of fish removed from the lake are available.

8.3 THREATS TO THE FISHERIES

Climate change

The temperature in the Lake Victoria Basin region is predicted to increase by 3 °C to 4 °C by the end of the twenty-first century, without much change to the rainfall, leading to a decrease in lake level because of enhanced evaporation (Sewagudde, 2009). Water levels in the lake have dropped by 1 m to 2 m due to climatic factors; climate warming has also been attributed to ecosystem changes that have led to increased eutrophication and changes in lake productivity (Phoon *et al.,* 2004).

Overexploitation and illegal fishing

Lake Victoria fishery shows classic indicators of intensive fishing. Declining catches of Nile perch have been attributed to the use of small-meshed nets, indiscriminate gear and mass targeting of fish (Abila, 2003). Catches of Nile perch are dominated by small juvenile fish with more than 95 percent of the catch below the size of first maturity. Most of the fish caught are also smaller than the recommended slot size of 50 cm to 85 cm (Njiru *et al.,* 2008). The mean weight of Nile perch decreased from 50 kg to 100 kg in 1981 to 5 kg to 10 kg in 1996 (O'Riordan, 1997) and catch per boat gear declined from about 80 kg/boat/day to 45 kg/boat/day (Matsuishi *et al.,* 2006). Changes in fish population parameters are also the result of the open-access nature of the fishery that has led to increased numbers of fishers, boats and illegal gear usage. The total number of fishers increased from 130 000 in 2000 to 195 000 in 2010 and the number of boats increased from 42 500 in 2000 to 65 000 in 2010 (Kolding *et al.,* 2014).

The high cost of fishing gear and theft of legal fishing gear are among some of the reasons some fishers use illegal fishing gear. Fishers have resorted to the use of cast nets, monofilament nets, beach seine nets and smaller meshed nets (which are cheaper to purchase than larger meshed nets) (Njiru *et al.,* 2008). Beach seine nets are particularly damaging along the nearshore areas as they disrupt spawning and nursery grounds. Declines in CPUE have essentially made fishing with legal gear unprofitable; if fishers cannot afford to invest in fishing technologies (outboard motors or gillnets), they resort to illegal fishing practices (Muhoozi, 2002). The use of active gillnetting within the Lake Victoria Basin is illegal, however 85 percent of boat fishing in the inshore area of the Ugandan portion of Lake Victoria actively used gillnets as reported by Muhoozi (2002).

Invasive species

The introduction of predatory Nile perch into Lake Victoria has contributed towards the extinction of around 200 species (Seehausen *et al.,* 1996). By the time the Nile perch had become established within the lake, the contribution of haplochromines to the fish biomass had declined from 90 percent to less than 1 percent (Geheb *et al.,* 2008; Kolding *et al.,* 2014). The introduction of Nile tilapia decimated native tilapias through genetic swamping and competition that forced native tilapia to near extinction (Geheb *et al.,* 2008).

Water quality

Rapid population growth, agricultural growth and discharge of urban and industrial waste into the catchment have contributed to the pollution and nutrient enrichment of the lake leading to algal blooms, stratification, anoxia and periodic mass fish kills (Hecky *et al.,* 1994; Mwanuzi *et al.,* 2005; Njiru *et al.,* 2008). Land runoff and atmospheric deposition account for 90 percent of phosphorus and 95 percent of nitrogen input into the lake (Scheren *et al.,* 2000). Pollution problems are only likely to get worse in light of the large population growth increases within the Lake Victoria Catchment (2 percent to 4 percent annually over most the basin, 5 percent to 10 percent annually in urban areas), which are some of the largest population increases globally (Scheren *et al.,* 2000).

8.4 EQUIVALENT FOOD REPLACEMENT

Local communities of Lake Victoria can be characterized as being food insecure (Abila, 2003; Geheb *et al.,* 2008). Unrestricted fish trade has contributed to food insecurity and reduced the population's nutritional status by removing fish through exports that otherwise would be available to lakeside consumers. The Lake Victoria Basin is characterized by entrenched poverty, recurrent droughts and environmental degradation. These factors have been attributed to declining land productivity, crop failures, soil degradation, desertification, loss of biodiversity, declining fisheries and crop disease; as such it has become difficult to produce sufficient food (Abila, 2003).

Given the declining fish catches and threats to food security within the Lake Victoria Basin, cost replacement estimates were established for 50 percent fish loss in capture fisheries based on catch estimates from the LVFO 2016 total of 1 061 107 tonnes (Table 8-2). Replacement foods consist of aquaculture (farmed tilapia), livestock, (beef, pork and chicken) and crops (maize and cassava).

Table 8-3. Food production (tonnes), water (km³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Tilapia	313 889 (423.2)	0.94 (10.4)	14 267 (20.7)	0.08
Beef	329 411 (35.0)	5.08 (56.1)	38 008 (7.5)	20.62
Pork	172 278 (113.9)	1.01 (11.4)	23 942 (4.6)	0.09
Chicken	542 559 (373.7)	2.34 (26.0)	14 558 (2.9)	1.28
Maize	697 125 (5.35)	0.85 (9.4)	1 242 (0.5)	0.03
Cassava	393 649 (30.9)	0.72 (7.9)	350 (0.1)	

Energy replacement (Table 8-3)

Aquaculture is in the early stages of development on Lake Victoria and current production of farmed tilapia is small (74 165 tonnes in 2015); consequently, replacement of fisheries production with farmed tilapia is equivalent to 423.2 percent of what is currently being produced. Similarly, pork and chicken replacement would also require an increase in production equivalent to ≥100 percent of current food production (2014 pork and chicken production was 151 137 tonnes and 145 188 tonnes, respectively). Maize replacement would require the largest production increase, but as maize production in the basin countries is high (13.0 million tonnes in 2014), the replacement figure is small (5.35 percent).

Water demand (Table 8-3)

Replacement of capture fisheries with alternative foods would result in a significant increase in water withdrawals from the riparian states. Replacement of fisheries with beef would have a large impact on water security in the basin countries, as the replacement amount would be equivalent to 56.1 percent of agricultural water use in the basin countries (agricultural water use was 9.04 km³ 1998-2017). Such high replacement water demand may not be achievable within the African Great Lakes region, as increased desertification in some areas would lead to increased physical water scarcity and economic water scarcity in all countries in the region by 2025.

Land requirements (Table 8-3)

Replacement of capture fisheries with farmed tilapia would require major land conversion, equivalent to 20.7 percent of the area of Lake Victoria, but as aquaculture technologies and efficiencies advance this figure should decrease. Pastureland area within the basin countries was 506 150 km² and arable land area was 262 000 km² in 2014. Chicken replacement would require the smallest land conversion and beef replacement the largest land conversion from a terrestrial food replacement.

Greenhouse gas emissions (Table 8-3)

Carbon emissions from 50 percent of the capture fisheries of the Lake Victoria Basin were estimated at 2 million tonnes. Replacement of fisheries with beef would have the largest impact on emissions with an additional 20.62 million tonnes of carbon. Chicken replacement would have the second largest emissions intensity, considerably more than the other replacement foods.

8.5 FISHERIES MANAGEMENT

The LVFO is central to the development of coordinated activities and policies within the basin.

Regional management strategies

A fisheries management plan was developed in 2001. The plan included programmes for regulating fishing pressure; harmonization of activities; adoption of the FAO Code of Conduct for Responsible Fisheries; strengthening of institutional capacity; promoting international fish trade; and developing proper handling, preservation, processing and storage of fish and fish products (Kolding *et al.,* 2014).

A regional plan of action to prevent and eliminate illegal, unregulated and unreported fishing in Lake Victoria was adopted in 2004. The plan included slot size landings of 50 cm to 85 cm to protect juvenile stocks; minimum legal mesh size for gillnets of 127 mm for Nile perch; closed seasons and protected areas; a total ban on beach seines, cast nets and trawling; ongoing collection of fisheries statistics; and monitoring studies of tilapia and Nile perch (LVFO, 2007).

The Nile Perch Fisheries Plan (2015–2019) aims to achieve more sustainable Nile perch fisheries by ending open access, reducing illegal fishing and establishing clear user rights with an overall reduction in fishing effort of 15 percent to 20 percent. More specifically, it stipulates fishing vessel registration, slot sizes, gillnet mesh-size restrictions and prohibition of monofilament and beach seine usage (FAO, 2015).

A co-management approach was initiated as part of the Lake Victoria Environmental Management Project. Local management bodies known as beach management units (BMUs) were established in United Republic of Tanzania, which were quickly introduced all over the lake and operational guidelines were developed (Ogwang, Medard and Ikwaput-Nyeko, 2004). The BMUs are technically responsible for ensuring that no fishing violations take place in their area of jurisdiction and that breeding areas are protected (Ogwang, Medard and Ikwaput-Nyeko, 2004). Their roles include ensuring that beaches are kept clean; assisting in data collection and documenting fisheries information; inspecting and recording visiting boats; proposing fisheries by-laws for district authorities and enforcing them (Kolding *et al.,* 2014). However, fisher compliance until now has not been resolved by the introduction of co-management. The use of illegal fishing methods is still very common. Essentially, the co-management approach is centrally controlled and influenced by international markets and local communities are not involved in co-determining the objective of the fishery but are expected to comply with regulations (Geheb, 2000).

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9 LAKE TANGANYIKA

9.1 OVERVIEW

Situated in the Rift Valley, Lake Tanganyika is shared by Burundi, Democratic Republic of Congo, United Republic of Tanzania and Zambia (Table 9-1). The lake extends for 676 km in length from north to south and the average width is 50 km. It is the largest and the deepest Rift Lake (maximum depth of 1 470 m and mean depth of 580 m) in Africa. The lake holds an estimated 18 980 km^3 of water, making it the largest lake in Africa and second largest in the world by volume. The lake has three major inflows from the rivers Ruzizi, Malagarasi and Kalambo and an insignificant inflow from the Lukanga River (Irvine, Etiegni and Weyl 2018).

Table 9-1. Characteristics of Lake Tanganyika

Country	Area of the lake (km^2)	Percent area of the lake in countries	Population of the lake
Democratic Republic of Congo	14 670	45	
United Republic of Tanzania	13 366	41	
Burundi	2 608	8	
Zambia	1 956	6	
Total	**32 600**	**100**	**10 000 000[1]**

[1] Irvine, Etiegni and Weyl (2018).

Fish diversity

Lake Tanganyika is one of the richest freshwater ecosystems in the world. According to FishBase there are 356 species in Lake Tanganyika; the most abundant family is Cichlidae (205 species) of which 183 are endemic and overall there are 231 endemic species in the lake (FishBase, 2017).

9.2 FISHERIES OVERVIEW

Fish is estimated to account for 25 percent to 40 percent of the total animal protein supply for people within the four Tanganyika states (Gréboval, Bellemans and Fryd,1994). Historically, the lake has supported one of the world's most productive pelagic fisheries, with fisheries being an important source of both nutrition and revenue to the bordering countries (O'Reilly *et al.,* 2003). Lake Tanganyika supports both artisanal and commercial fisheries, with commercial ventures exploiting clupeids such as the Lake Tanganyika sardine (*Limnothrissa miodon*), Lake Tanganyika sprat (*Stolothrissa tanganicae*) and the sleek lates (*Lates stappersii*) (Mölsä *et al.,* 1999; Magnet, Reynolds and Bru, 2000). Most of the lake's commercial fishery is made up of the clupeids (approximately 65 percent) and lates (approximately 35 percent). Poor infrastructure and natural barriers within the basin constrain fish processing and marketing possibilities. Steep escarpments and poor road links mean that out of necessity, most fish landed must be processed in some form in order to extend shelf-life; sun-drying is the most common method as it is easily managed under local conditions and requires few inputs (Mölsä *et al.,* 1999). Recreational fishing is permitted in the Nsumbu National Park in the Zambian portion of the lake, where once a year the Zambia National Game Fishing Competition is held on the bank of the lake; the economic output generated from this sport fishing is used to fund conservation within the park (Sinyinza, Chomba and Lindley, 2000).

Fishing methods

Artisanal fisheries consisting of traditional fishing units known as *lusenga* that use scoop nets, gillnets and hand lines predominate (Mölsä *et al.,* 1999; Magnet, Reynolds and Bru, 2000) and are used mainly for subsistence fishing (Magnet, Reynolds and Bru, 2000). Commercial fishing activities use mechanized lift nets, purse seine nets and beach seines (Mölsä *et al.,* 1999). In Zambia, beach seines are banned everywhere except on Lake Tanganyika (Sinyinza, Chomba and Lindley, 2000).

Fish trade

Reliable statistics are generally lacking on the amount of fish in the various marketing channels beyond the basin. Major marketing outlets for dried fish are from Shaba Province of the Democratic Republic of Congo, the Zambian Copperbelt and north of the lake to Rwanda (Mölsä *et al.,* 1999). In United Republic of Tanzania, fish is an immensely popular food, where most of the national catch goes to domestic consumption, but a large unrecorded amount of dried fish is exported to neighbouring countries. Due to the high rates of endemism amongst cichlid and non-cichlid fishes, the lake is well established in the ornamental fish trade (Mölsä *et al.,* 1999). The annual earnings from Lake Tanganyika fisheries are estimated to be between USD 80 million to USD 100 million (Mölsä *et al.,* 1999).

Employment

Table 9-2 indicates estimated participation in fishery activities on Lake Tanganyika. According to Paffen *et al.* (1997) there were 44 957 active fishers on Lake Tanganyika in 1995. Results from a 1997 survey indicated that most fishers were men (Mölsä *et al.,* 1999). However, women are well represented in the postharvest sector and comprise most of the small-scale processors and traders in Zambia and Democratic Republic of Congo (Mölsä *et al.,* 1999). However, income levels are much lower in the postharvest sector compared to the harvest sector, and national income for women is well below national per capita averages (World Bank, 1999).

Table 9-2. Participation in Lake Tanganyika fishing activities

Country	Fishers (year)	Processing/trade (year)	Total
Democratic Republic of Congo	26 300 (1995)		26 300
United Republic of Tanzania			
Burundi	3 500 (1997)	9 500 (1997)	13 000
Zambia	8 430 (2011)		8 430
Total	**38 230**	**9 500**	**47 730**

Sources: FAO (2009); Department of Fisheries, Ministry of Fisheries and Livestock, Zambia, (2016).

Note: Blank indicates no data available.

Estimated fish production

Table 9-3 gives the estimated fisheries production of Lake Tanganyika for the lake countries. In Burundi freshwater fish catches come almost entirely from Lake Tanganyika (Magnet, Reynolds and Bru, 2000), but have been variable. Variability in the fish catch in Burundi can be attributed to political disruption, especially in the mid-1990s, but overall fluctuations appear to be due to variability in the catch of *L. miodon* and *S. tanganicae* which culminated in a decline in catch from the mid-2000s (Irvine, Etiegni and Weyl, 2018).

FAO estimates fishery catches from Lake Tanganyika at between 165 000 tonnes to 200 000 tonnes annually (Magnet, Reynolds and Bru, 2000). Generally, Lake Tanganyika's fish stock levels are characterized by year-to-year and area-to-area fluctuations, which are normally associated with changes in the abundance of clupeids and *Lates* species (Mölsä *et al.,* 1999). Fluctuations may be caused by variable success in fish recruitment, because of changes in the strength and timing of nutrient upwelling and resultant plankton success. Fishing effort is not equivalently distributed along the lake; the northern and southern extremities are subject to the greatest fishing pressure (Mölsä *et al.,* 1999).

Table 9-3. Production estimates for Tanganyika countries

Country	Catch estimate (tonnes)	Year	Reference
Democratic Republic of Congo	90 000	1995	Coenen, Paffen and Nikomeze (1998)
United Republic of Tanzania	55 000	1995	Coenen, Paffen and Nikomeze (1998)
Burundi	9 000	1999	Magnet, Reynolds and Bru (2000)
Zambia	12 609	2015	Department of Fisheries, Ministry of Fisheries and Livestock, Zambia, (2016)
Total	**166 609**		

Status of the fisheries: catch trends

In the Burundian waters of the lake, the total recorded catch increased from the early 1950s to the mid-1960s, reaching a maximum total catch of 24 000 tonnes in 1992, after which fishery production began to decline. Catches in Burundi have declined to around 9 000 tonnes due to civil unrest and restrictions on fishing (Magnet, Reynolds and Bru, 2000). In Burundi CPUE of commercial fishing units dropped from 166 kg in 1994 to 111 kg in 1996, similarly in Zambia and Democratic Republic of Congo the CPUE declined by roughly 50 percent between 1994 and 1996 (Coenen, Paffen and Nikomeze 1998).

Zambia has also experienced an increase in fishing effort and a decline in fish yield from 20 000 tonnes in 2009 to 12 609 tonnes in 2015 (Department of Fisheries, Ministry of Fisheries and Livestock, Zambia, 2016).

Aquaculture

At present, there is little or no information concerning aquaculture within Lake Tanganyika. In the Democratic Republic of Congo, Burundi and United Republic of Tanzania aquaculture is generally not well developed, practices are based on small-scale pond aquaculture within each country.

Recreational fishing

Sport fishing is permitted after paying a fee in the Nsumbu National Park in Zambia. This catch is thought to be minimal in terms of quantity and of mature fish. Sport fishers mainly use rod and line on the lake, but other gear is also sometimes used. The target fish are *Luciolates angustifrons* and the goliath tigerfish (*Hydrocynus goliath*), although catches of the latter are becoming rare (Sinyinza, Chomba and Lindley, 2000).

9.3 THREATS TO THE FISHERIES

Climate change

Local records of air temperature from the Lake Tanganyika region show warming consistent with global patterns; records show a temperature rise of 0.5 °C to 0.7 °C in air temperatures and a predicted rise of 1.3 °C to 1.7 °C within the next 80 years (Hulme *et al.,* 2001). The climate of the lake is important for ensuring upwelling of nutrient-rich waters. During the dry season, strong southerly winds cause upwelling of nutrient-rich waters and a weaker thermocline provides most of the limited nutrients to the lake (Coulter, 1991). The lake itself has experienced a warming trend of 0.1 °C ± 0.01 °C decade-wise since 1913; also wind velocities have decreased by 30 percent since the 1970s. These combined impacts have increased the stability of the lake and reduced the essential nutrient mixing, subsequently causing a decline in primary production, postulating a cause for a decline in the lake's pelagic fishery (O'Reilly *et al.,* 2003).

Overexploitation and overfishing

Lake Tanganyika fisheries essentially function under an open access system, which can lead to overexploitation (Mölsä *et al.,* 1999). Excess fishing pressure of Lake Tanganyika sprat has been observed in the northern end of the lake in Burundi. Furthermore, the excessive use of highly unselective beach seine nets in the Zambian portion of the lake has heavily targeted juvenile Lake Tanganyika sardines throughout their inshore nursery grounds (Mannini, 1998). Beach seines have also inflicted damage on the cichlid coastal fish community (Mölsä *et al.,* 1999). Declining stocks of sleek lates in the Zambian and northern portions of the lake have resulted from heavy commercial fishing; as such, the sleek lates constitute approximately 20 percent of the commercial catch in these areas (Mannini, 1998).

9.4 EQUIVALENT FOOD REPLACEMENT

The importance of fish for nutritional welfare is critical in the Lake Tanganyika region. Strong population growth within the basin and indeed throughout Africa drives demand for fish. Food security in this region is regarded as vulnerable due to the occurrences of droughts and other natural disasters. Demand for fish has also increased in United Republic of Tanzania and Democratic Republic of Congo because of disruptions to crops and livestock production by civil conflict and population displacements (Magnet, Reynolds and Bru, 2000).

Based on estimated fisheries production in Table 9-3 replacement estimates were calculated for a 100 percent loss to the fishery. This is based on no information concerning the status of the fisheries and any perceived significant decreases in fish catches. Replacement estimates for livestock (beef, pork and chicken), aquaculture (tilapia) and agricultural crops (wheat, maize and cassava) were established.

Table 9-4. Food production (tonnes), water (km^3), land (km^2) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km^3 (percentage of agricultural water use)	Land required to replace fisheries in km^2 (percentage of inland water area/ pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Tilapia	98 569 (390.1)	0.29 (3.8)	4 480 (1.9)	0.03
Beef	103 444 (18.2)	1.59 (20.6)	11 935 (2.7)	6.47
Pork	54 100 (66.2)	0.32 (4.2)	7 377 (1.7)	0.03
Chicken	170 378 (145.5)	0.74 (9.5)	4 571 (1.0)	0.40
Maize	218 916 (68.4)	0.27 (3.5)	390 (0.09)	0.09
Wheat	261 120 (1.9)	0.48 (6.2)	788 (0.2)	0.08
Cassava	123 616 (0.5)	0.23 (2.9)	109 (0.02)	

Energy replacement (Table 9-4)

Due to the lower nutrient content of agricultural crops, replacement of capture fisheries with crops would require the largest increases in production. To replace the kilojoules from capture fisheries with the crops in Table 9-4 would require the equivalent of 68 percent, 2 percent and 0.5 percent of the current production respectively (production in 2014 was 281 815 tonnes, 11.39 million tonnes and 22.83 million tonnes for wheat, maize and cassava, respectively). Replacement of kilojoules from capture fisheries with farmed tilapia would require the equivalent of 390.1 percent of current production (in 2014 farmed tilapia production was 25 266 tonnes). Chicken production as replacement would require an increase, equivalent to 145 percent of current poultry production (production in 2014 was 117 129 tonnes).

Water demand (Table 9-4)

Water resources would be strained through the replacement of capture fisheries with alternative food sources. Beef as replacement demand would be equivalent to 20.6 percent of the agricultural water withdrawals from the countries that share Lake Tanganyika (agricultural water use was 6.1 km^3 1998-2002). Pork and farmed tilapia production would require the smallest water demand, equivalent to 3.8 percent to 4.2 percent of agricultural water withdrawals. Replacement of capture fisheries with crops would require a smaller water demand than replacement with terrestrial livestock.

Land requirements (Table 9-4)

Tilapia aquaculture would require land requirements, equivalent to 1.9 percent of the total drainage basin area of the lake. Providing conditions within the lake are suitable, tilapia farming could directly replace capture fisheries within the lake. Beef production would require the largest land-use change equivalent to 2.7 percent of total pastureland from lake countries (pastureland area in 2014 was 446 830 km^2). Replacement crop production would require the equivalent of 0.02 percent to 0.2 percent of arable land from lake countries (arable land area was 456 630 km^2 in 2014).

Greenhouse gas emissions (Table 9-4)

Carbon emissions from Lake Tanganyika capture fisheries were estimated at 626 449 tonnes, with replacement foods resulting in additional carbon emissions. Farmed tilapia, pork and chicken production would produce fewer emissions compared to other food sources with additional emissions of 25 645 tonnes, 29 922 tonnes and 403 555 tonnes of carbon. Beef production would result in the largest net increase in emissions from an animal source of 6.47 million tonnes of carbon.

9.5 FISHERIES MANAGEMENT

National management plans

Lake Tanganyika essentially functions under an open access system and local management strategies are near non-existent. The need to restrict fishery access for stock management in Lake Tanganyika has been recognized for decades, as the open access nature has led to overexploitation of fish stocks.

In Burundi fisheries management authority and enforcement are restricted due to budget shortages. Fisheries laws are based on colonial-era decrees, which are outdated and incomplete. External funding attempts to improve fisheries statistics has had no lasting impact as national follow-up activities are not funded. In the Democratic Republic of Congo, fisheries legislation consists of colonial-era decrees; the years of civil conflict have confounded the creation of effective legislation. In United Republic of Tanzania, the Tanzanian Fisheries Research Institute aims to enhance sustainable exploitation of fishery resources, however, management constraints stem from budget limitations and the remote location of fishery areas.

Transboundary management

The Lake Tanganyika Authority Action Plan (2013) includes strategies for restricting access to the fishery and a monitoring, control and surveillance system (Van der Knaap *et al.,* 2014) but no effective actions have been evident. The institutional structures relating to the lake are currently too weak to expect any notable management in the near future. Cooperation and management among Lake Tanganyika countries have been targeted through the Tanganyika Regional Fisheries Programme and implementation of the Framework Fisheries Management Plan. The programme aims to:

- Implement co-management initiatives and encourage stakeholder involvement in fisheries development;
- Improve infrastructure, roads, jetties and marketing facilities;
- Protect stocks and biodiversity, introduce appropriate gear and environmental education; and
- Establish a regional management entity (the Lake Tanganyika Fisheries Centre).

Through this management plan, responsible fishing is enhanced through some form of fishing licensing, introduction of gear restrictions and working with local fisheries to establish no-take zones to protect fish stocks. The Lake Tanganyika fisheries centre provides enhanced regional cooperation and is responsible for fisheries-related matters and zone management (Magnet, Reynolds and Bru, 2000).

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10 LAKE MALAWI

10.1 OVERVIEW

The waterbody is known as Lake Malawi in Malawi, Nissa in Mozambique and Nyasa in United Republic of Tanzania. Lake Malawi is the third deepest (maximum depth 700 m, mean depth 264 m) and ninth largest lake by surface area (28 800 km^2 to 30 800 km^2) (Table 10-1). From north to south the lake stretches for 505 km to 603 km with a maximum width of 87 km. The lake holds 8 400 km^3 of water, roughly 7 percent of the world's total available surface water. Despite the lake's large size, the lake does not have a high outflow water volume. Of the 68 km^3 of water that enters the lake from more than 200 rivers, only about 16 percent flows out through the Shire River and a small tributary that joins the Zambezi River (Bootsma and Jorgensen, 2005; Weyl, Ribbink and Tweddle, 2010). The lake is permanently stratified into three layers, being anoxic below depth of about 170 m to 200 m (Weyl, Ribbink and Tweddle, 2010).

Table 10-1. Characteristics of Lake Malawi

Country	Area of the lake (km^2)	Percent area of the lake in countries
Malawi	18 000	60
Mozambique	6 500	21
United Republic of Tanzania	5 700	19
Total	**30 200**	**100**

Source: Weyl, Ribbink and Tweddle (2010).

Fish diversity

Lake Malawi is the most species-rich lake in the world, containing about 800 species (Ribbink, 2001). It is estimated that there are 3 000 recognizable fish. There are 14 families of fish, cichlids comprising over 90 percent, of which 99 percent of the cichlids are endemic (Ribbink, 2001). Several cichlids are economically important such as the sardine-like pelagic cyprinid *Engraulicypris sardella.* The variety and diversity of cichlids are mainly represented by mouth brooding haplochromines which are generally divided into the coloured mbuna and non-mbuna (Turner, 1995).

Fish introductions

Lake Malawi has not experienced exotic fish species introductions such as those that have altered the fish communities of other lakes such as Lake Victoria. Lungfish and the trout-like *O. microcephalum* are the only documented successful introductions to Lake Malawi (Ribbink, 2001).

10.2 FISHERIES OVERVIEW

The lake's fisheries are characterized by diversity in species composition, fishing techniques and mode of utilization (Banda *et al.,* 2001). Although the export of live fish for aquarium trade provides an important source of employment and revenue to the local economy, most of Lake Malawi's fish is harvested for food by industrial and artisanal fisheries (Weyl, Ribbink and Tweddle, 2010). The artisanal sector comprises highly commercialized, small-scale ventures that support village communities. In Malawi, fisheries monitoring has shown continuous growth of the artisanal sector. Industrial purse seining for chambo began in Southern Lake Malawi in 1943 (FAO, 1976). A decline in the nearshore chambo fishery led to an expansion in offshore pelagic fisheries. By the 1990s the artisanal fishery was harvesting pelagic fish stocks previously thought to be underexploited (Weyl, Ribbink and Tweddle, 2010). After 2000, the fishery increasingly focused on offshore stocks, with catches mainly consisting of

E. sardella (Irvine, Etiegni and Weyl, 2018). The artisanal catch comprises more than 180 species (Irvine *et al.,* 2002). The main target fish species for the artisanal fisheries, depending on the fishing gear, are chambo (*Oreochromis* spp.), kambuzi (*Haplochromis* spp.), usipa (*E. sardella*), utaka (*Copadichromis* spp.), kampango (*Bagrus meridionalis*) and mlamba (*Clarias gariepinus*).

Fishing methods

The artisanal fishery sector uses beach seines, open water seines locally known as *chilimira* nets, gillnets, traps and longlines. Most artisanal fishing is conducted in the inshore area, due to the lack of offshore fishing gear (Malawi Government, 2002). Fishing vessels range from plank boats with or without engines to dugout canoes (Weyl, Nyasulu and Rusuwa, 2005). Artisanal fishing increased in the lake between 1999 and 2003; the number of gillnets almost doubled and the number of open water seines increased by 25 percent. There has been a similar growth in United Republic of Tanzania (Irvine *et al.,* 2002) and Mozambique (Halafo, Hecky and Taylor, 2004).

Fish trade

Malawian cichlids, especially the highly coloured mbuna, are the main targets for the ornamental fish trade. In Lake Malawi, ornamental fishing licences are restricted to two businesses, one based in Senga Bay and the other in Chipoka (Bootsma and Jorgensen, 2005). In 2014, the ornamental fish trade generated USD 316 255 (African Great Lakes, 2020). In Malawi, fisheries are marketed locally at the point of landing. Fishers have little bargaining power over the price of their catch, fish traders dominate marketing activities and function as a source of informal credit. Fresh fish are auctioned, but most of the catch is preserved by smoking, roasting or sun-drying. (FAO, 2005)

Employment

Employment data are generally lacking from the basin countries. Weyl, Manase and Banda (2000) estimated that there were around 48 800 fishers from the Malawian portion of Lake Malawi, but no other estimates from other countries were available.

Estimated fish production

Despite the importance of the lakeshore communities to the three riparian states, none of the countries monitor fisheries with the accuracy or effectiveness that is required to develop informed management strategies (Darwall and Allison, 2002). Attempting to assess the status of one of the most species-rich freshwater fisheries in the world is complicated by multispecies interactions in the fisheries (Weyl *et al.,* 2010). It is estimated that lake fisheries from the basin countries could yield about 80 000 tonnes/year, but at least 44 000 tonnes/year are harvested from Malawi (Table 10-2) (Weyl, Ribbink and Tweddle, 2010). Only Malawi has a continuous time series catch and effort data that at best can be used to highlight trends in the fisheries. As such, no information regarding fisheries catches in Mozambique and United Republic of Tanzania has been obtained. Total fish catch is difficult to estimate due to the many small-scale fishers and the government's limited capacity to collect data (Bootsma and Jorgensen, 2005). Most of the catch in Malawi (80 percent) from Lake Malawi is from the artisanal sector.

Table 10-2. Fishery production estimate for Malawi

Catch estimate (tonnes)	Year	Reference
44 000	n/a	Weyl, Ribbink and Tweddle (2010)

Status of the fisheries: catch trends

Available data indicate a decreasing catch trend and declining biodiversity, particularly in southern Lake Malawi (Weyl, Ribbink and Tweddle, 2010). Fishing pressure is high on the Malawian flank of the lake, especially the southern portion; the Mozambican side has a low population density therefore fishing pressure is low (Bootsma and Jorgensen, 2005). Catches of larger more valuable species have declined dramatically, especially around the southern arm of the lake where historically, fish catches have been greatest. These include catfish, mpasa, nchila and chambo, the most valuable component of the fishery.

Although catch from the Malawian side has been relatively stable, increasing fishing effort has resulted in decreased catch rates, the depletion of larger more valuable species and species changes. The fishery yielded between 5 000 tonnes to 9 000 tonnes/year from southern Lake Malawi until 1992, but subsequently the annual catch decreased to 2 000 tonnes/year with loss of habitat and overfishing cited as causes (Weyl, Ribbink and Tweddle, 2010).

Aquaculture

On Lake Malawi, there are two aquaculture sectors: the smallholder and commercial sectors. The Fisheries Act prohibits the use of exotic species in aquaculture within the Lake Malawi Basin. Aquaculture is based on indigenous tilapiine cichlids. Smallholder aquaculture production was in the region of 50 tonnes to 120 tonnes/year (Andrew, Weyl and Andrew, 2003). Commercial aquaculture production is limited to one-cage culture operation that in 2009 produced 400 tonnes of fish (Weyl, Ribbink and Tweddle, 2010).

Recreational fishing

In Malawi, the state-run Lake Malawi National Park, which extends into the lake, is popular for tourism where recreational activities such as sport fishing take place. Participation is negligible and is confined to hook and line. But recreational fishers have full access to Malawian waters within the national park (Allison and Mvula, 2002).

10.3 THREATS TO THE FISHERIES

Climate change

Climate change within the Lake Malawi region has received little attention to date; climate change has occurred within the basin and will likely become more pronounced over the coming decades. Using historical deep-water temperature data, Vollmer (2002) showed that the hypolimnion warmed from 22.02 °C to 22.74 °C between 1939 and 1999. At shallower depth, the temperature at 100 m increased from 23 °C to 23.7 °C. This may seem insignificant but could be important given that the lake is weakly stratified during the cold season. Warming of surface waters more than the deeper waters could reduce the vertical mixing and result in less nutrient supply, lower plankton production and a decline in fish production (Bootsma and Jorgensen, 2005).

Overfishing

Fish catch from the Malawian section of the lake has remained relatively stable at around 30 000 tonnes/year, however this has been maintained through increased fishing effort and decreased mesh sizes; as a result the CPUE has declined giving an indication of overexploitation (Weyl, Ribbink and Tweddle, 2010). Overfishing is a major concern in Malawi but is not considered a problem in Mozambique or United Republic of Tanzania (Bootsma and Jorgensen, 2005). Artisanal fishers who use beach seines and gillnets account for 85 percent to 90 percent of the annual catch; these fishers are considered a threat to the biodiversity of the lake as they mostly exploit inshore fisheries due to the lack of offshore fishing gear (Malawi Government, 2010).

Catches of larger more valuable species have declined dramatically. Declines in catfish and chambo fisheries have been attributed to overfishing, while the decline of potadromous fish is likely due to a combination of overfishing and habitat loss (Bootsma and Jorgensen, 2005). Chambo was caught mainly in southern Lake Malawi with gillnets and beach seines. The fishery collapsed between 1992 and 1999 and now constitutes only 20 percent of the total catch (Irvine *et al.,* 2002).

10.4 EQUIVALENT FOOD REPLACEMENT

The fishery sector provides vital and unique nutritional benefits for millions of people. Before the decline of chumbo fisheries from the lake, the fishery sector contributed around 70 percent of the dietary animal protein of the people in Malawi (Bland and Donda, 1995). According to FAO, 28 percent of animal protein consumed within Malawi is fish (FAO, 2011). Overexploitation and increased fishing pressure effort by many fishers has decreased fish consumption from 14 kg/capita/year in the 1970s to less than 6 kg/capita/year in 2010 (Malawi Government, 2010). Given that most fish caught in Malawi come from Lake Malawi, food replacement estimates were calculated based on a scenario of 50 percent loss in Lake Malawi capture fisheries (based on basin production in Table 10-2). Food replacement sources consist of livestock (beef, pork and chicken), aquaculture (tilapia) and crops (maize, wheat and cassava).

Table 10-3. Food production (tonnes), water (million m³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (thousand tonnes)
Tilapia	13 015 (159.9)	38.9 (0.5)	591 (2.0)	3.39
Beef	13 659 (3.7)	210.6 (2.6)	1 546 (8.5)	855.17
Pork	7 143 (2.7)	42.7 (0.5)	974 (5.2)	3.95
Chicken	22 497 (13.6)	97.3 (1.2)	603 (3.3)	53.28
Maize	28 906 (18.3)	35.3 (0.4)	51 (0.02)	1.15
Wheat	34 479 (0.3)	62.9 (0.8)	104 (0.05)	1.13
Cassava	16 323 (0.1)	29.8 (0.4)	14 (0.006)	

Energy replacement (Table 10-3)

The Lake Malawi countries are large producers of wheat and cassava, so as a proportion of current production, replacement production is small (0.3 percent and 0.1 percent) (wheat and cassava production in 2014 was 10.87 and 15.02 million tonnes respectively). Aquaculture within the Lake Malawi countries is not well developed, and production is low, as such the amount required to replace kilojoules from capture production is equivalent to 160 percent of current production (production in 2015 was 8 183 tonnes).

Water demand (Table 10-3)

Replacement of inland fisheries would lead to increased water abstraction to produce other food sources. Beef as a replacement would have the largest impact on freshwater resources, equivalent to 2.6 percent of total water withdrawals from Lake Malawi countries (agricultural water use from Lake Malawi countries was 6.9 km³ 1998-2002). This value is nearly double the water demand for chicken production which is equivalent to 1.2 percent of water withdrawals.

Land requirements (Table 10-3)

Farmed tilapia production would require land-use conversion, equivalent to 2.0 percent of the drainage area of the basin. The expansion in aquaculture under a scenario of loss of 50 percent of the fisheries could be met through expanding existing aquaculture activities within the lake. Terrestrial livestock would require 1 546 km², 974 km² and 603 km² for beef, pork and chicken respectively, equivalent to 3.3 percent to 8.5 percent of the total pastureland area (pastureland area in 2014 was 698 500 km²).

Greenhouse gas emissions (Table 10-3)

Carbon emissions from capture fisheries in Lake Malawi were estimated at around 82 720 tonnes. Replacement of fisheries with beef would have the largest impact on carbon emissions of 0.85 million tonnes. Wheat as replacement would result in the smallest net increase in carbon emissions of 1 130 tonnes.

10.5 FISHERIES MANAGEMENT

National and regional management plans

The three riparian countries have strong fisheries legislation with institutions that have direct mandates for research. Legislation mainly mandates allowable fishing gear and requirements for licensing of gear and boats. In Malawi and Mozambique, the Fisheries Conservation and Management Regulations enforce closed fishing season areas, mesh-size restrictions, minimum size of fish, maximum headline length of fishing nets and licensing of fishing gear. In United Republic of Tanzania, the National Fisheries Policy aims to enhance knowledge of fisheries resources; improve fisheries product utilization; encourage and support initiatives leading to protection of fish stocks; and improve the involvement of fisher communities.

Management of the artisanal sector is changing from the conventional top-down management approach to the community participation fisheries management approach. The Fisheries Act recognizes that the unique biodiversity of the lake is essential and fisheries can potentially endanger this. As a result, permits are required for the introduction of any non-indigenous fish and within the Lake Malawi Basin, alien species are banned from introduction (Weyl, Ribbink and Tweddle, 2010). The Lake Malawi National Park, which is the world's only freshwater, underwater national park has a 100 m zone that is closed to fishing to protect the highly coloured mbuna fish (Bootsma and Jorgensen, 2005).

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11 CONGO–ZAIRE RIVER

11.1 OVERVIEW

The Congo River (Table 11-1) is the second longest river in Africa (4 700 km) and second largest river in the world. It has the second greatest discharge (average of 41 000 m^3/s) of any river in the world after the Amazon (Nkounkou and Pobst, 1987). The sources of the Congo River are located in the highlands of the East Africa Rift system and Zambia, with one tributary draining into Lake Tanganyika and one into Lake Mweru (Zambia and Democratic Republic of Congo). Other major tributaries in the Upper Congo system are the Chambeshi River (Zambia) and the Uele and Lualaba rivers (both Democratic Republic of Congo) in the upper reaches. Through the Congo River's middle reaches from Boyoma Falls to Malebo Pool (the Congo and Democratic Republic of Congo), the river crosses the equator and crosses the Cuvette Centrale Congolaise, a large expanse of lowland rain forest that contains swamps and wetlands that stretch 190 000 km^2 over the Congo and Democratic Republic of Congo (Hughes and Hughes, 1992). The Congo River's largest tributaries are the Ubanji and Sangha rivers (the Congo and Democratic Republic of Congo).

Table 11-1. Characteristics of the Congo–Zaire River Basin

Country	Basin area (km^2)	Percent area of the basin in countries	Populations of the basin countries	Population density/km^2
Democratic Republic of Congo	2 313 350	61.1	74 015 747	32
Central African Republic	403 570	10.7	3 463 480	9
Angola	285 395	7.5	2 702 229	9
Congo	246 977	6.5	2 971 565	12
United Republic of Tanzania	244 593	6.4	6 516 612	40
Zambia	177 735	4.7	3 233 242	19
Cameroon	96 395	2.5	795 489	8
Burundi	14 574	0.4	5 028 315	367
Rwanda	6 464	0.2	1 877 328	412
Total	**3 789 053**	**100**	**100 604 007**	**101**

Fish diversity

Fish diversity of the Congo River and some of its tributaries is outlined in Table 11-2. The Congo River has more species than any other African river system and is only second to the Amazon in terms of diversity (Banister, 1986). This reflects the wide range of biotopes within the basin, ranging from wide rivers to shallow riffles and swamps (Banister, 1986). Over 1 000 species are estimated to reside in the Congo River, of which 80 percent are endemic (Thieme *et al.,* 2005), of these, only around 50 species are regularly captured. There are nine introduced species in the Congo–Zaire River; they are: the African bonytongue (*Heterotis niloticus*), *Halpochromis aeneocolor*, the three-spotted tilapia (*Oreochromis andersonii*), *Oreochromis leucostictus*, the Kariba tilapia (*Oreochromis mortimeri*), the Nile tilapia (*Oreochromis niloticus*), the Sabaki tilapia (*Oreochromis spilurus*), the mosquitofish (*Gambusia affinis*), and the guppy (*Poecilia reticulate*) (FishBase, 2017).

Table 11-2. Fish diversity in the Congo River and tributaries

Waterbody	Fish diversity	Endemic	Introduced
Congo River	1 012	624	9
Lake Mweru	172	25	2
Malebo Pool	165	-	-
Ubanji River	263	19	2
Sangha River	233	8	-
Kwango River	95	9	-
Kasai River	279	23	1
Uele River	207	7	2
Lualaba River	259	15	3

Source: FishBase (2017).

11.2 FISHERIES OVERVIEW

The Congo River Basin is one of the largest in the world, but fisheries information is minimal or in some cases non-existent (Nieland and Béné, 2008). Lake Mweru is an important commercial pelagic fishery and demand for fish is high in the nearby Copperbelt and Katanga Province mining districts. The lake contains taxa of demersal fishing interest (e.g. *Tilapia* spp. and *Enteromius* spp.). Fisheries of Lake Mweru are characterized by a rapid expansion in effort, lack of effective control measures, decline in catches of favoured species and anomalous maintenance of production levels through switching to less valuable species. Women and men have gender-differentiated roles in fishing activities, where men fish individually while women fish collectively (Béné *et al.,* 2009). Fishing effort is dispersed over the basin, with groups of fishers operating from small villages and temporary camps. Fishing is not carried out all year with the same intensity; the main fishing periods are the 'short' and 'long' dry seasons (January to March and July to September, respectively) (Béné *et al.,* 2009).

Fishing methods

Within the basin, FAO reports from the 1980s indicated that traditional fishing methods, using unmotorized canoes, gillnets, seine nets and hand lines were common in the basin. In Lake Mweru, gillnets and longlines are the main gear in the demersal fishery, while boat and beach seines are used in the lamp fishery of the demersal fishery (Béné *et al.,* 2009). In rural areas, fishing is strongly gender-differentiated, with men engaging in fishing using passive gear (hooks and gillnets) and women fishing collectively using a traditional method known as écopage, which uses basket traps known as *eboko* (Béné *et al.,* 2009).

The Salongo National Park, in the central region of the Congo Basin in the Democratic Republic of Congo, is considered a high priority conservation area for freshwater fish (Toham *et al.,* 2003). Illegal fishing practices are widespread, consisting of chemical poisoning and burning of large areas of *Pandanus* (Ingowabini, 2005). There is no control over net mesh sizes and small-meshed nets (1 cm to 2 cm) are frequently used. There is also no limitation on the number of nets per fisher, with some fishers using up to 100 nets each night (Inogwabini, 2005). Congolese legislation limits mesh sizes (Corsi, 1984), but law enforcement is poor. Clearing and burning of land are unsustainable as there is no selectivity in the fish caught and this results in the destruction of fish-breeding sites (Inogwabini, 2005).

Fish trade

Small fishing villages and temporary fishing camps in the Congo River Basin mainly use fish for local consumption with most of the fish catch reaching markets in Kinshasa (Democratic Republic of Congo). Fish demand in the Copperbelt and Katanga Province mining districts is high; a high portion of fish catch from the Congo Basin goes to these regions. Inland catches are marketed in cured form, either as smoked, sun-dried or salt-dried, except for markets in the immediate vicinity of landing sites, where fresh products are available (FAO, 2009).

Employment

Employment data in the fishing industry for the Congo River Basin is sparse. It is estimated that 20 percent of the adult population living in rain forests is engaged in river fisheries (Brummett *et al.,* 2004). From 1984 to1989 it was estimated that there were 62 000 permanent fishers in the Congo River Basin (Nieland and Béné, 2008). More recent estimates suggested that 60 000 fishers are permanently employed in fisheries in the Congo region (WorldFish Centre, 2008).

Estimated fisheries production

Table 11-3 indicates the estimated fishery catches from the Congo River and the major tributaries and lakes that form the Congo River Basin. Despite the importance of fisheries within the basin, information concerning fisheries is minimal. Years of civil war and political instability within the region have meant that constructing a reliable picture of the current state of fisheries within the basin is challenging. Fisheries administration within the Democratic Republic of Congo effectively does not exist and statistical information on specific waterbodies is lacking or outdated (USAID, 2010) (Table 11-3). Research has shown that fish catches from Lake Mweru and Lake Tumba have declined considerably since the 1970s, following the nationalization of several industrial fishing operations.

Table 11-3. Production estimates for Congo River tributaries and other waterbodies

River/floodplain/lake	Catch estimate (tonnes)	Year	Country	Reference
Congo–Zaire (whole system)	119 500	1980–1984	DRC*, CAR**	Nieland and Béné (2008)
Lualaba	72 500	n/a	DRC	
Luapula	8 800	1983	DRC	
Ubanji	7 520	1984	Congo, DRC, CAR	
Sangha	15 000	1983	Congo	
Tributaries and floodplains	10 000–15 000	n/a	Cameroon, DRC, Congo, CAR	
Likouala	15 000	n/a	Congo	Welcomme (1985)
Malebo Pool	3 000–3 500	1984	DRC	Van den Bossche and Bernacsek (1990)
Lake Mweru	5 953	1983	DRC, Zambia	Konare (1984)
Lake Tumba	1 500	1982	DRC	Corsi (1984)
Total	**139 273–144 773**			

Note: The total does not include the Congo–Zaire (whole system) value, as it is uncertain which tributaries constitute the whole system catch.

*DRC = Democratic Republic of Congo

**CAR = Central African Republic

Aquaculture

Fish farming was introduced to the Congo Basin in 1946 and enjoyed some success under colonial rule (*Tilapia rendalli* and *Oreochromis macrochir* farmed in Lake Mweru), but after independence with no public support the sector crashed (Micha, 2013). Currently, semi-intensive and intensive fish production systems have yet to be developed. Lack of development plans, fish feed industries and difficult access to capital funding have hampered the development of fish farming (Micha, 2013).

Recreational fishing

Trophy sport fishing within the Congo Basin has been growing in popularity over the last decade, with large exotic species such as crocodiles and the goliath tigerfish being the main target of sport fishers. Local commissioners issue sport fishing permits to any person fishing for recreational purposes (FAO, 2001). The high diversity of fish species in the Congo River makes them attractive as aquarium fish, particularly from the Malebo Pool.

11.3 THREATS TO THE FISHERIES

Overexploitation and illegal fishing methods

Illegal fishing practices within the Congo Basin include the use of fine-meshed gillnets and seine nets, chemical poisoning of ponds, and burning and clearing of large areas of *Pandanus*. Indeed, chemical fishing and burning are likely to affect both fish and human consumers and dynamite fishing depletes fish stocks and kills young fish and fish of commercial importance, and thus is a threat to native fish species (Inogwabini, 2005; Thieme *et al.,* 2005). Fishing pressure in the middle Congo region is high, especially around areas of high population density like Mbandaka. Surveys in the region in 2003 revealed 74 percent of the catch comprised four species, which were mainly juveniles, indicating fish stocks were already exploited (Thieme *et al.,* 2005).

Water quality

Water pollution has been described as one of the most important human-induced reasons for reductions in relative fish abundance in the tropics (Inogwabini, 2014). Aveling *et al.* (2003) suggested that pollution of surface and groundwaters was responsible for high levels of heavy metal pollution in fish from the basin in the Democratic Republic of Congo. However, these high pollution levels were documented in waters adjacent to towns and in the absence of sewage treatment. The lower Congo River has a high human population density, which impacts the river through pollution, especially around Malebo Pool. The small poeciliid *Poropanchax myersi* is classed as endangered as it is endemic to Malebo Pool, in which the entire population has been impacted by the impact of raw sewage and industrial waste (Stiassny *et al.,* 2011).

Hydropower development

Most power generated within the Congo River Basin comes from hydropower (Winemiller *et al.,* 2016). Hydropower dams present a severe threat to freshwater fisheries, particularly to species that show seasonal migrations along the river, including several species of cyprinids and distichodontids (Stiassny *et al.,* 2011). In the lower Congo River region the Inga dams, a series of four cascading dams, and the planned Grand Inga Dam would divert water and reduce the water flow for at least 20 km downstream of the dam (Winemiller *et al.,* 2016) potentially impacting on fish populations.

11.4 EQUIVALENT FOOD REPLACEMENT

Fish is a major source of food and an important economic asset in the Congo River Basin (Inogwabini, 2014). Fish provides 75 percent to 80 percent of local communities' animal protein and is the main source of animal protein for local communities within the basin (Nieland and Béné, 2002; Thieme *et al.,* 2005; Morra, Hearn and Buck, 2009). Decreasing water levels and in some areas (Ingowabini *et al.,* 2006), rapid demographic increase and dire economic conditions have pushed local communities to rely more on fishing to generate income. This has contributed to decline in fish species and fish stocks in many bodies of water (USAID, 2010).

Given the lack of more recent fisheries catch information, the widespread use of chemicals for fishing, intensive logging and planned expansion in hydropower within the region, replacement estimates were established for a 50 percent loss in the total capture fisheries production from Table 11-3 (the average of maximum and minimum production being 142 023 tonnes). Replacement estimates for livestock (beef, pork and chicken), aquaculture (tilapia) and crops (maize and cassava) were established.

Table 11-4. Food production (tonnes), water (km³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Tilapia	41 568 (149.1)	0.12 (1.3)	1 889 (0.05)	0.01
Beef	43 623 (4.8)	0.67 (6.9)	5 033 (0.004)	2.73
Pork	22 814 (7.9)	0.14 (1.4)	3 111 (0.002)	0.01
Chicken	71 850 (33.9)	0.31 (3.2)	1 928 (0.002)	0.17
Maize	92 319 (0.6)	0.11 (1.2)	164 (0.01)	0.004
Cassava	52 130 (0.1)	0.09 (1.0)	46 (0.004)	

Energy replacement (Table 11-4)

Replacement of capture fisheries from the Congo River with crops would require the largest increase in production. The Congo River Basin countries are high producers of maize and cassava, therefore the percentage proportion of replacement food to current food production is small (0.6 percent and 0.1 percent, respectively) (15.44 million tonnes and 40.59 million tonnes for the Congo Basin countries in 2014). Beef and farmed tilapia production would require similar production figures to replace kilojoules from capture fisheries, equivalent to 4.8 percent of current production for beef (production in 2014 from Congo Basin countries was 906 497 tonnes). However, aquaculture in many of the basin countries is not well established and consequently the replacement value of 41 000 tonnes would be equivalent to 149.1 percent of current farmed tilapia production from the basin countries (farmed tilapia production from the Congo Basin countries in 2015 was 36 416 tonnes).

Water demand (Table 11-4)

Beef as a replacement food source would have the largest impact on freshwater resources, equivalent to 6.9 percent of all the water abstractions from the Congo River Basin countries (agricultural water use was 9.70 km³ 1998-2002). Farmed tilapia and pork production would require similar amounts of water for production, equivalent to 1.3 percent and 1.4 percent of water abstractions from the basin countries. Crops would require less water for replacement than livestock and aquaculture; maize and cassava production would require 1.2 percent and 1.0 percent of water abstractions from the basin countries respectively.

Land requirements (Table 11-4)

The Congo River Basin is one of the largest river basins by area in the world and the countries that make up the basin contain large areas of arable and pastureland. Farmed tilapia would require land conversion, equivalent to 0.05 percent of the area of the Congo River Basin. Beef production would require the largest land conversion from terrestrial livestock, equivalent to 0.004 percent of the total pastureland area from the riparian countries (the pastureland area in 2014 was 1.14 million km²). Maize and cassava would require 164 km² and 46 km² of land respectively to replace capture fisheries, equivalent to 0.01 percent and 0.004 percent of arable land within the riparian countries (arable land area in the basin was 1.15 million km² in 2014).

Greenhouse gas emissions (Table 11-4)

Carbon emissions from the Congo River Basin capture fisheries were estimated at 264 181 tonnes. Replacement of capture fisheries with alternative sources would result in a net increase in carbon emissions. Replacement of capture fisheries with beef would result in the highest additional carbon emissions of 2.73 million tonnes. Followed by chicken production (0.17 million tonnes), pork (0.01 million tonnes), farmed tilapia (0.01 million tonnes) and maize cropping (0.004 million tonnes).

11.5 FISHERIES MANAGEMENT

Given the importance of fish as a source of food and an economic asset in the Congo River Basin, management strategies for fisheries are surprisingly lacking, and existing legislation is generally outdated.

International management

The African Convention on the Conservation of Nature and Natural Resources revised objectives in 2003 to enhance environmental protection and sustainable use of natural resources. In a key article 'Species and Genetic Diversity,' parties must protect the aquatic environment with a view to minimizing any practice that may adversely affect the aquatic habitat. Parties must adopt legislation to ensure the sustainable use of aquatic resources, through closed seasons and prohibition of indiscriminate means of fishing (DLA Piper, 2016).

National management strategies

The basic legislation on fisheries for the Democratic Republic of Congo remains the 1937 Decree on Fishing and Hunting which enables authorities to grant exclusive fishing rights in a designated area to any person. A regulation of this Decree in 1981 prohibited fishing with explosives, electrical devices or toxic substances throughout the Democratic Republic of Congo and provided for the seizure of such articles. A 1979 regulation introduced fishing permits and fees, with conditions of prohibition on discarding fish, and mesh-size restrictions for industrial fishing; however, the use of beach nets is legal (USAID, 2010).

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12 ZAMBEZI RIVER

12.1 OVERVIEW

The Zambezi River (Table 12-1) is the largest river in Southern Africa (Moore *et al.,* 2007) and fourth longest river in Africa, with mean annual discharge of about 97 km^3 (Moore *et al.,* 2007). The river is divided into the Upper, Middle and Lower Zambezi (Tweddle, 2010). The river is sourced in Zambia (World Bank, 2010) and contains many noticeable features, such as Victoria Falls, Kafue Flats and Lake Kariba. The basin of the Zambezi River is described in terms of 13 sub-basins representing major tributaries and segments (World Bank, 2010). Some of these major tributaries are the Kafue, Luangwa, Bangweulu, Chobe and Shire rivers. The Zambezi River forms a large floodplain delta with numerous oxbows and swamps before entering the Indian Ocean (World Bank, 2010). The wet season lasts from October to April, but due to rainfall distribution, northern tributaries contribute more towards the river flow than southern tributaries. For instance, the Upper Zambezi sub-basin, Kafue, Luangwa and Shire rivers contribute 60 percent of the total Zambezi River discharge (World Bank, 2010).

Table 12-1. Characteristics of the Zambezi River Basin

Country	Area of the basin (km^2)	Percent of the river basin area in countries	Population of the river basin	Population density/km^2
Zambia	575 628	41.9	12 919 544	22
Angola	255 820	18.6	668 664	3
Zimbabwe	212 533	15.5	10 236 651	48
Mozambique	156 944	11.4	4 294 607	27
Malawi	110 159	8.0	15 270 979	139
United Republic of Tanzania	27 697	2.0	1 768 732	64
Botswana	17 030	1.2	22 700	1
Namibia	17 091	1.2	105 891	6
Total	**1 373 289**	**100**	**45 299 131**	**38**

Fish diversity

According to FishBase there are 199 species in the Zambezi River Basin and the most abundant family is Cyprinidae (46 species). There are also nine endemic species within the basin (FishBase, 2017). This differs from diversity estimates from Skelton (1994) who found 165 species of freshwater fish in the basin. Elsewhere in the basin, the Lower Shire River has 63 recorded species (Tweddle and Willoughby, 1979). The Luangwa River in the Middle Zambezi contains a recorded 61 species, one of which is endemic (*Oreochromis mortimeri*) (Marshall, 2000).

Fish introductions

Recorded exotic species in the basin are: kapenta (*Limnothrissa miodon)*, rainbow trout (*Oncorhynchus mykiss)*, brown trout (*Salmo trutta)*, smallmouth yellowfish (*Barbus aeneus*), (*Barbus natalensis*), goldfish (*Carrassius auratus*), common carp (*Cyprinus carpio*), mosquitofish (*Gambusia affinis*), bluegill (*Lepomis macrochirus*), guppy (*Peocilia reticulate*), green swordtail (*Xiphophorus hellerii*) and largemouth bass (*Micropterus salmoides*) (FishBase, 2017). A recent addition to the list of the exotics has been the cichlid *Oreochromis niloticus* (WorldFish, 2007).

12.2 FISHERIES OVERVIEW

Fisheries in the Zambezi River are hugely varied: artisanal, medium-scale, inland, lake-based and riverine versions all exist within the basin. Fish production on floodplains is related to the magnitude and duration of floods, with the highest catches occurring during low floods when waters recede and fish concentrations are high (Tweddle, 2010). Subsistence and commercial fishing and angling tourism are major activities throughout the system's large lakes and floodplains (Tweddle, 2010). High-value species in the Zambezi River are cichlids such as; *Oreochromis andersonii*, *Tilapia rendalli*, *Serranochromis* spp., but also African tigerfish (*Hydrocynus vittatus*) and African catfish (*Clarias gariepinus*) (Tweddle, 2010). More recently, smaller species such as *Schilbe intermedius, Marcusenius altisambesi, Brycinus lateralis* and small *Barbus* have been sold at markets indicting a diversification of fishing methods (Tweddle, 2010). The construction of dams in the Middle Zambezi led to the creation of lake systems that have become important commercial fisheries, particularly for kapenta in Lake Kariba, Lake Itezhi-tezhi and Lake Cahora Bassa. Lake Liambezi, is also a productive fishery, but migrant fishers dominate here and most of the processed fish is marketed directly to entrepreneurs in the Democratic Republic of Congo, who hire fishers to fish for them (Tweddle *et al.,* 2015).

Fishing methods

Subsistence fishing methods include basket fishing, which is operated mainly by women, traps of various kinds, hook and line and spear fishing. Boats and gillnets were introduced in the early 1980s when the government introduced grants and finance schemes to assist the industry (Mosepele, 2001). The dominant fishing gear used in the Kafue fishery is gillnets (25 mm to 50 mm stretched mesh), but longlines, traps and seine nets are also used. The use of seine nets is banned in Namibia and restrictions are imposed on the use of gillnets, but these restrictions are largely ignored. Unsustainable fishing pressures and population growth have led to the prolific use of unsustainable fishing methods such as mosquito-meshed nets, small-meshed nets, monofilament nets and drifting gillnets. Indeed, some 47 percent of gillnets in use on the Kafue River was found to be below permissible mesh sizes (Tweddle *et al.,* 2015).

Fish trade

There are currently no exact figures concerning the trading of fish within the Zambezi Basin and surrounding region. The fisheries sector contributed around 1 percent to the GDP (USD 109 million in 2007) in Zambia (Musumali *et al.,* 2009). There is considerable demand for fish in Zambia with domestic markets mainly centred in urban areas in the Copperbelt Province. The most important regional market for fish trade is the Democratic Republic of Congo where close proximity and high fish prices make this market highly competitive compared to domestic markets (Musumali *et al.,* 2009).

Employment

The estimated participation in fisheries within the Zambezi Basin is outlined in Table 12-2. There are few estimates available on fishery employment in the basin, but it is thought that the fisheries sector provides income for over 300 000 people (Musumali *et al.,* 2009). In Zambia, an estimated 8 430 people are involved in processing and trade, although this is likely an underestimation (Department of Fisheries, Zambia, 2016). Women are discouraged from participation in fisheries due to limited access to fishing permits and capital, cultural issues and gender stereotypes. Women mainly work in the postharvest sectors marketing and processing fish (Chali, Musuka and Nyimbili 2015). There is no information available on the participation of anglers in sport or recreational fishing; however, it is thought that the numbers are substantial.

Table 12-2. Estimated participation in fisheries in the Zambezi River Basin

Country/waterbody	Number of fishers	Reference
Zambia	62 766	Department of Fisheries, Zambia (2016)
Kafue Floodplain	4 000	Tweddle (2010)
Lake Itezi-tezhi	1 250	Kolding (2007)
Total	**68 016**	

Estimated fisheries production

Table 12-3 indicates the estimated fisheries production for the Zambezi and its major tributaries and lakes from various literature sources. Fish catches from the Zambian portion of the Zambezi have generally been increasing. The 2015 catch statistic for the Bangweulu River was the largest catch since 1995, but catches have experienced almost biannual drops in fish production; for instance, fish catches in 2008 were 16 301 tonnes, which dropped to 12 522 tonnes in 2009 (Department of Fisheries, Zambia, 2016). Fish catches for the Kafue River have declined from peak catches in 2008 (7 302 tonnes) to current production of 4 490 tonnes. Catch composition in 2015 on the Bangweulu River was dominated by cichlids and tilapias which constituted 28 percent and 22 percent of the catch by weight respectively. On the Itezhi-tezhi Reservoir the catch mostly comprised *Oreochromis* spp. (32 percent), followed by Cyprinidae (16 percent) and *Schilbeidae* spp. (16 percent).

Table 12-3. Production estimates for the Zambezi River

<table>
<tr><th>Waterbody</th><th>Estimated fish catch (tonnes)</th><th>Year</th><th>Country</th><th>Reference</th></tr>
<tr><td>Zambezi River (whole system)[1]</td><td>83 719[1]</td><td rowspan="6">2015</td><td rowspan="8">Zambia</td><td rowspan="6">Department of Fisheries, Zambia (2016)</td></tr>
<tr><td>Upper Zambezi River</td><td>6 109</td></tr>
<tr><td>Lower Zambezi River</td><td>920</td></tr>
<tr><td>Bangweulu River</td><td>17 849</td></tr>
<tr><td>Lake Kariba</td><td>11 309</td></tr>
<tr><td>Itezhi-tezhi Reservoir</td><td>2 752</td></tr>
<tr><td>Kafue Floodplain</td><td>4 490[2]–8 907</td><td>Unknown</td><td>Van den Bossche and Bernacsek (1990)</td></tr>
<tr><td>Luapula River</td><td>8 804</td><td>Unknown</td><td>Turpie et al. (1999)</td></tr>
<tr><td>Luangwa River</td><td>786</td><td>1980</td><td>Malawi and Zambia</td><td>Coopconsult-Propesca (1982)</td></tr>
<tr><td>Zambezi Delta</td><td>16 264</td><td>Unknown</td><td>Mozambique</td><td>Turpie et al. (1999)</td></tr>
<tr><td>Lake Liambezi</td><td>2 700</td><td>2011–2012</td><td>Namibia and Botswana</td><td>(R. Peel, personal communication)</td></tr>
<tr><td>Cahora Bassa Reservoir</td><td>4 343</td><td>1982</td><td>Mozambique</td><td>Van den Bossche and Bernacsek (1990)</td></tr>
<tr><td>Chobe–Caprivi Floodplain</td><td>1 273</td><td>1994–1995</td><td>Namibia and Zambia</td><td rowspan="3">Turpie et al. (1999)</td></tr>
<tr><td>Shire River/Floodplain</td><td>9 750</td><td>Unknown</td><td>Malawi and Mozambique</td></tr>
<tr><td>Barotse Floodplain</td><td>5 874</td><td>1995</td><td>Zambia</td></tr>
<tr><td>Total</td><td>93 223–97 640[3]</td><td></td><td></td><td></td></tr>
</table>

[1]The Zambezi (whole system) consists of fish catches from Zambia only.

[2]Kafue Floodplain production of 4 490 tonnes from Zambia alone from 2015.

[3]Total production excludes the Zambezi River (whole system) total.

The commercial kapenta fishery on Lake Cahora Bassa fishery peaked around 2004 and low product price made the fishery economically non-viable (Barnes *et al.,* 2002). Most companies were struggling to survive due to escalating production costs and decline in CPUE. Artisanal and subsistence catch was at 4 000 tonnes/year which is equivalent to the estimated sustainable yield (Tweddle, 2010). As some of the data in Table 12-3 are old, it is likely that the production estimates are overestimated, given the decline in fish yield that has occurred over many years, as observed by Tweddle *et al.* (2015) and other authors.

Except for the larger fisheries in lakes and on floodplains, fishing effort and catches go unrecorded. Catch and effort data are patchy and in many cases unreliable, even for the larger fisheries. The Zambia Department of Fisheries collects statistical data on the floodplain fisheries but recognizes that the data are unreliable; the department is handicapped by a lack of resources necessary to enable it to update the system and implement improvements (Tweddle, 2010).

Status of the fisheries: catch trends

General catch trends throughout the basin show a decline in catch rates, a rise in fishing effort by increasing numbers of fishers and decreases in catch/fisher. Fish catches have been declining throughout these fisheries despite a series of high flood years between 2007 and 2011 on the Caprivi Floodplain. The decline in catches has mainly been attributed to major increases in fishing effort, overfishing, environmental conditions and the invasion of water hyacinth in the Zambezi Delta. On the Caprivi Floodplain, fishing methods have shifted from multifilament nets to monofilament nets to compensate for the increased fishing effort. The CPUE recorded within the fishery indicated a decline from 7 kg net/night to just over 1 kg net/night between 2010 and 2012 (Tweddle *et al.,* 2015) and stock decline of valuable cichlid species was estimated at more than 90 percent between 2010 and 2012 (Tweddle *et al.,* 2015).

Aquaculture

Aquaculture production is on the increase within the basin in Zambia, increasing 18 percent between 2014 and 2015 (19 281 tonnes and 22 753 tonnes, respectively) (Department of Fisheries, Zambia, 2016). Major aquaculture production systems are ponds, cages and pens in isolated areas.

Recreational fishing

Angling opportunities are some of the most important interests for tourists, particularly in the Eastern Caprivi in Namibia. Also, the Zambezi and Chobe rivers contain fish that appeal to recreational fishers such as the African tigerfish (*H. vittatus*) (Næsje *et al.,* 2001).

12.3 THREATS TO THE FISHERIES

Climate change

Projections for the basin range from modest to more severe impact estimates. The Intergovernmental Panel on Climate Change (IPCC) anticipates a basin-wide increase in temperature of up to 2.9 °C annually and as high as 4.1 °C seasonally, although annual precipitation is projected to increase only slightly across the basin with seasonal decreases of 10 percent to 15 percent by 2050 (IPCC, 2008). Increases in temperature are predicted to cause a significant reduction in stream flow, with estimates predicting that runoff will decrease by 26 percent to 40 percent by 2050 (International Rivers, 2012).

Increasing fishing pressure/overfishing

Increasing human population pressure is also a cause of major fisheries decline. Tweddle *et al.* (2015) found that fishing pressure was intense in areas of high human population. Observed fish at markets in Malabo showed many fisheries were overexploited as catches had shifted to low-value smaller fish in the absence of larger more valuable fish, formerly the focus of the fishery (Peel *et al.,* 2013; Tweddle *et al.,* 2015). The increase in illegal gear use on the Kafue River and floodplains and drastic increase in the number of fishers, coupled with the relatively stable catches suggest the CPUE has declined. The weight of fish caught per gillnet has declined from 3 kg in 1980 to 0.2 kg since 2000. In terms of the number of fish per gillnet, this had declined from 20 fish/net to just 2 fish/net in 2005. There has also been a fall in the maximum size of fish caught (Tweddle *et al.,* 2015). All of these factors suggest a fishing down process, linked to the loss of larger individuals (Tweddle *et al.,* 2015).

12.4 EQUIVALENT FOOD REPLACEMENT

Fish are described as the most important natural resource within the basin (Turpie *et al.,* 1999). Fish are important to rural communities, where consumption is five times the national average (Van Gils, 1988). Despite this, some fisheries within the basin have seen fish yields decline by over 50 percent. Illegal and damaging fishing methods are now commonplace in many fisheries as an ever-increasing population continues to exploit the Zambezi fishery beyond its capacity. Due to the observed threats equivalent food replacements were estimated based on the scenario of a 50 percent loss in the fishery, based on the average Zambezi total catch outlined in Table 12-3; the results are given in Table 12-4. Food replacement sources consist of livestock (beef, pork and chicken), agricultural crops (maize and cassava) and aquaculture (tilapia).

Table 12-4. Food production (tonnes), water (million m³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilocalories from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilocalories from fisheries (percentage of current food production)	Water required to replace fisheries in million m³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Tilapia	28 229 (67.7)	84.5 (0.6)	1 238 (0.1)	0.007
Beef	29 625 (3.3)	456.7 (3.3)	3 418 (0.2)	1.85
Pork	15 493 (5.5)	92.8 (0.7)	2 112 (0.1)	0.009
Chicken	48 753 (16.0)	211.6 (15)	1 309 (0.06)	0.11
Maize	35 403 (0.1)	76.6 (0.6)	111 (0.02)	0.002
Cassava	74 783 (0.4)	64.8 (0.5)	31 (0.007)	

Energy replacement (Table 12-4)

Crop replacement would require the largest production increase to replace kilocalories from fisheries as crops are generally nutrient-poor. But maize and cassava production from the riparian countries is high (16.0 million tonnes and 18.8 million tonnes, respectively), consequently the replacement values constitute a small percentage of current production. Tilapia replacement would require the largest increase in terms of current food production because aquaculture practices are still relatively undeveloped in the riparian countries and tilapia production in 2015 was 41 695 tonnes.

Water demand (Table 12-4)

Replacement of kilocalories from capture fisheries with livestock would place a higher demand on water resources than replacement with crops or aquaculture. Beef replacement would require the largest water demand, while pork, tilapia, maize and cassava replacement would require the smallest water demand. Crops would require the smallest water demand as the other food sources need water for feed. However, agricultural water use for the basin countries was high at 13.8 km³ (FAO, 2016), consequently the replacement values are low compared to current water use.

Land requirement (Table 12-4)

Replacement food sources would require a significant expansion in land for production, with tilapia requiring the largest land conversion, as aquaculture intensification practices are not well developed in some basin countries. Improvement in aquaculture technologies and efficiency could see this value reduced. Agricultural land area within the riparian countries is extensive, hence the replacement amounts are small compared to land currently in use. Pastureland area in 2014 was 2.1 million km² and agricultural land area was 473 490 km².

Greenhouse gas emissions (Table 12-4)

Estimated carbon emissions from 50 percent of capture fisheries from the Zambezi River were 179 412 tonnes. Net increases in carbon emissions for replacement of fisheries with alternative food sources would be highest for beef production, with farmed tilapia and rice production replacement resulting in the smallest emissions' increase.

12.5 FISHERIES MANAGEMENT

National management strategies

Most countries within the Zambezi Basin have legislation governing involvement in fisheries. In Zambia, the Department of Fisheries manages fisheries through the Fisheries Act (FAO, 2006). The laws provide for closed seasons, gillnet mesh-size restrictions, implementation of permanently closed areas and a ban on destructive fishing methods; the Fisheries Act also encourages community participation in fisheries management. The Namibian Inland Fisheries Resources Act, 2003 provides management for inland fisheries. Seine nets are banned and restrictions on gillnet fishing are imposed, however, these are widely ignored. In Zimbabwe, fisheries management comes under the National Parks Act, 1975, which regulates the number of fishing licences, gear, area restriction and mesh sizes, however poaching is a major problem (FAO, 2016; Tweddle, 2010).

Community management strategies

Communities on the Barotse Floodplain created the Zambezi Fish Conservation Association and a fish traders' association in response to concerns over the decline in valuable cichlid species. This association also works in partnership with the Zambian Department of Fisheries, the Barotse Royal Establishment, and WorldFish to implement and fund co-management activities (Tweddle *et al.,* 2015). Also, communities on the shared Caprivi Floodplain in Namibia are taking control of their own natural resources through the establishment of conservancies; Fish Protection Areas have been established and are protected by wardens (Tweddle *et al.,* 2015).

Transboundary management strategies

The Zambezi River Commission developed the Integrated Water Resources Management (IWRM) strategy to promote equitable, sustainable and efficient management of water resources. One of the main components of the IWRM strategy is environmental management and sustainable development through which strategies to promote sustainable fisheries management have been established to tackle the issue of unsustainable and low productivity fisheries management. IWRM strategy targets are:

- Fishery development should be integrated with water resource development, particularly around reservoirs;
- Reservoir release operating rules to support floodplain fisheries;
- Investigate the scope for improving the fish productivity of Cahora Bassa Reservoir; and
- Make fishery development integral to reservoir development, promote good fish monitoring practices and improve data collection (Zambezi River Authority, 2008).

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13 LAKE KARIBA

13.1 OVERVIEW

Situated in southern Zambia and shared almost equally with Zimbabwe (Table 13-1). Lake Kariba is a man-made lake created by damming the Zambezi for hydroelectric power generation (Paulet, 2013). The lake is 77 km long with a catchment of 5 364 km^2 and a surface area of 5 350 km^2; it has a mean depth of 29 m and maximum depth of 120 m. The lake has a significant outflow of 50 km^3 to 65 km^3 relative to its volume (160 km^3) and the lake level fluctuates seasonally from annual floods between December and June (Kolding, Musando and Songore, 2003). The lake is multipurpose, besides providing electricity and fish, it is an important recreational and tourism area because of the abundant wildlife and water activities.

Table 13-1. Characteristics of the Lake Kariba Basin

Country	Area of the lake (km^2)	Percent area of the lake in countries	Population of the lake
Zambia	2 407.5	45	27 067
Zimbabwe	2 942.5	55	
Total	**5 350**	**100**	

Sources: Kolding, Musando and Songore (2003); Department of Fisheries, Ministry of Fisheries and Livestock, Zambia (2016).

Fish diversity

Presently there are 50 recorded fish species in the lake, five of which are introduced species (Kolding *et al.,* 2003). The most abundant families are Cichlidae (12 species) and Cyprinidae (9 species) (FishBase, 2017). The introduced species consist of the red breast tilapia (*Tilapia rendalli*), yellow-belly bream (*Serranochromis robustus*), longfin tilapia (*Oreochromis macrochir*), kapenta (*Limnothrissa miodon*) and the Nile tilapia (*Oreochromis niloticus*) (FishBase, 2017).

13.2 FISHERIES OVERVIEW

Fishing is very important for the lake communities. Districts surrounding the lake are mountainous and the soils are generally poor and therefore not rich enough to support substantial agriculture and livestock activities. As such, many people resort to fishing as their only means of income. Consumer surveys indicate that for rural communities, dried kapenta (*Limnothrissa miodon*) is one of few fish products that is readily available in rural areas (Chali, Musuka and Nyimbili, 2014).

The lake contains two distinct fisheries: one is a low-cost non-mechanized multispecies inshore fishery; the other a highly mechanized capital-intensive, semi-industrial single species offshore fishery for kapenta. There is little interaction between the two (Kolding, Musando and Songore, 2003).

The Zambian Government introduced kapenta about 150 km upstream of the dam between 1967 and 1969 (Magadza, 2006). Kapenta production increased rapidly after introduction and developed into a million-dollar industry (Kolding, Musando and Songore, 2003) and within five years the fish had completely colonized the lake (Chali, Musuka and Nyimbili, 2014). Kapenta fishing is a major economic activity in the district where few other opportunities are available. Commercial catches on the lake are seasonal; during the summer months (September to March) kapenta move inshore to protected bays to breed. Commercial pelagic kapenta catches increase again in March when adults return to open water (Chali, Musuka and Nyimbili, 2014).

Fishing methods

The commercial kapenta fishery is licence-controlled and highly mechanized. Monohaul and pontoon fishing are the most common pelagic commercial fishing methods. Some fishers also use fish finders to find large shoals of kapenta; about 19 percent of rigs has fish finders. Ring nets, catamaran tops and underwater lights are other commonly used fishing gear. The Department of Fisheries in Chilanga (Zambia) reported that the number of fishing companies had doubled from 86 in 2009 to 168 in 2013 (Chali, Musuka and Nyimbili, 2014).

Fishing effort on the lake is high due to the high participation in the industry. Chali, Musuka and Nyimbili (2014) reported that there were 800 rigs on the lake in 2013, however Paulet (2013) observed 632 rigs on the Zambian side of Lake Kariba alone and in 2011, Kinadjian (2012) observed more than 1 000 rigs in operation on the lake.

Fish trade

Trade from the lake is largely unknown, but the main source of fish exports is dried kapenta; demand is higher in rural areas as no refrigeration is needed. Given the importance of dried kapenta to rural communities it is reasonable to presume that most dried kapenta is traded domestically within the lake basin countries. Cage culture fish are exported to foreign markets in Europe and other countries in Southern Africa (FAO, 2007).

Employment

Information on gender involvement in fishing in Lake Kariba is lacking, however the commercial kapenta sector is largely dominated by men; 4 608 men compared to 46 women in Zambia and a total of 1 272 fishers in Zimbabwe (FAO, 2007; Department of Fisheries, Ministry of Fisheries and Livestock, Zambia, 2016). Women are discouraged from joining the active fishing sector as the industry is considered a male domain, in which a woman would feel inferior (Chali, Musuka and Nyimbili, 2014). Instead, women are mostly involved in processing and the postharvest sector; 6 percent of women involved in fisheries participated as shareholders alongside their male counterparts (Chali, Musuka and Nyimbili, 2014).

Estimated fisheries production

Table 13-2 indicates the estimated fisheries production from Lake Kariba for Zambia and Zimbabwe from official government sources in Zambia and from the literature in Zimbabwe. Of the 2015 total in Zambia over 50 percent of the fishery catch (6 345 tonnes) came from the kapenta fishery.

Fishing effort is not equitably shared between countries with Zambia harvesting 70 percent of fish and Zimbabwe 30 percent. FAO was involved in facilitating a dialogue between countries to reduce fishing effort and attain an agreed balance of 55 percent: 45 percent (Zimbabwe: Zambia) (Barson, 2010). Reported FAO statistics for fish catches on the Zambian side of Lake Kariba are considerably lower than those reported in Table 13-2, as annual fisheries harvests of around 3 500 tonnes were reported in 1982 (Van den Bossche and Bernacsek, 1990). By contrast FAO statistics for the Zimbabwean portion of Lake Kariba are nearly double those from Table 13-2, with 11 313 tonnes in 1981 (Marshall, 1982).

Table 13-2. Production estimates for Lake Kariba countries

Country	Catch estimate (tonnes)	Year	Reference
Zambia	11 039	2015	Department of Fisheries, Ministry of Fisheries and Livestock, Zambia (2016)
Zimbabwe	5 000[1]	1995	Mhlanga and Mhlanga (2013)
Total	**16 039**		

[1] Artisanal fisheries only.

Status of the fisheries: catch trends

Commercial catches of kapenta have been declining in general. Maximum sustainable yield was reached during peak harvest of 31 000 tonnes in 1990, after which harvests diminished steadily. Kapenta fishery catch declined from around 10 000 tonnes in 2009 to around 6 000 tonnes in 2012 (Kinadjian, 2012).

Catches/rigs on the Zambian side ranged from 0.302 tonnes to 0.124 tonnes/day, but dwindled as the number of fishers increased (FAO, 2012). A decline in fishing effort between 2003 and 2007 was accompanied by an increase in total catch (Kinadjian, 2012). The CPUE in Zimbabwe was approximately 50 kg/night/boat and the yield in Zambia was about 30 kg to 35 kg/night/boat (Chali, Musuka and Nyimbili 2014). Given the scale of commercial fishery catches within the lake, the statistics are expected to be reliable, however there is a substantial amount of illegal and unregulated fishing within the lake which goes unrecorded.

Aquaculture

To increase fish supply, small-scale cage fish farming is carried out along the shore of the lake. The main species farmed are redbreast tilapia, Mozambique tilapia, Nile tilapia and some carp species (Kautsky *et al.,* 1997). Water quality is good for cage culture. Aquaculture practices in Zambia are small with two cage farms (Blow and Leonard, 2007). In Zimbabwe, the Lake Harvest Aquaculture project for cage culture operations was established in 1997 and produces approximately 3 500 tonnes annually, most of which is exported to Europe (Blow and Leonard, 2007).

Recreational fishing

Lake Kariba is considered a tourist hotspot in a water-scarce area of Africa. Angling and sport fishing opportunities are a tourist attraction and the Annual International Tigerfish Tournament is the largest sport-fishing event in Zimbabwe (FAO, 2007). However, data are lacking on the impact of recreational fishing on fish stocks, as some sport fish, such as tigerfish, are also attractive for artisanal fishers and, as such, this fish is becoming rarer in the lake (Hesthagen, Sandlund and Næsje, 1994).

13.3 THREATS TO THE FISHERIES

Climate change

Lake Kariba has warmed by a mean of 1.54 °C between 1965 and 1990 and is projected to experience seasonal rates 2 °C higher than the 1990 baseline the IPCC indicated as likely to elicit significant ecosystem changes (Parry *et al.,* 2007). This could impact the productivity of Lake Kariba through stronger stratification leading to nutrient depletion that could lead to a change in phytoplankton species composition (Ficke, Myrick and Hansen, 2007).

Overexploitation and overfishing

Fishing on the Zimbabwean side of Lake Kariba is managed with closed areas and gear restrictions, but fishing on the Zambian side is unrestricted (Kolding, Musando and Songore, 2003). Poor management of the fishery on the Zambian side has contributed to the overexploitation of kapenta stocks (Jul-Larsen *et al.,* 2003). Overfishing of kapenta on the Zambian side of Lake Kariba is expanding, catches have decreased by almost 50 percent and the CPUE has also decreased. Paulet (2013) highlighted the lack of enforcement measures and resources within local government as one of the leading problems facing the fishery.

Invasive species

The invasive Australian red claw crayfish (*Cherax quadricarinatus*) escaped from nearby fish farms in Zambia in 2002 and has been spreading throughout the lake. The invasive species could be causing more damage than previously thought, as it hunts shoals of kapenta and will generally consume almost anything including plants, invertebrates and fish eggs. The possible migration of this species into other areas of the Zambezi Basin is a concern, as it has the potential to disrupt the ecosystem structure of invaded waters (Marufu, Phirl and Nhiwatiwa, 2014; ZAMCOM *et al.,* 2015). The inevitable escape of Nile tilapia from cage culture has resulted in the decline of native tilapiines in Lake Karibasuch; for example, the Kariba tilapia (*Oreochromis mortimeri*), endemic to the Middle Zambezi, has disappeared from Lake Kariba (Tweddle, 2010).

13.4 EQUIVALENT FOOD REPLACEMENT

Commercial kapenta fishing is important for maintaining food security in rural communities around Lake Kariba. However, the Lake Kariba fisheries are overexploited by an increasing number of fishers, particularly on the Zambian side, which has led to a reduction in fish catches. Given the decline of kapenta fisheries from 31 000 tonnes in 1990 to just over 6 000 tonnes in 2015, replacement estimates were modelled on a 50 percent loss of the Lake Kariba fishery based on the fisheries total from Table 13-2. Replacement food sources consist of aquaculture (tilapia), livestock (beef, pork and chicken) and crops (cassava, wheat and maize).

Table 13-3. Food production (tonnes), water (million m^3), land (km^2) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m^3 (percentage of agricultural water use)	Land required to replace fisheries in km^2 (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (thousand tonnes)
Tilapia	4 744 (15.9)	14.2 (0.3)	216 (4.0)	1.23
Beef	4 979 (1.4)	76.7 (1.5)	574 (0.2)	311.73
Pork	2 604 (4.6)	15.6 (0.3)	355 (0.1)	1.44
Chicken	8 200 (7.3)	35.5 (0.7)	220 (0.07)	19.42
Maize	10 537 (0.2)	12.9 (0.3)	18 (0.02)	0.42
Wheat	12 568 (5.0)	22.9 (0.4)	37 (0.05)	0.41
Cassava	5 950 (0.5)	10.9 (0.2)	6 (0.007)	

Energy replacement (Table 13-3)

Replacement of capture fisheries with agricultural crops would require the largest increases in production to replace capture fisheries, with wheat production requiring the equivalent of 5.0 percent of current production in Zambia and Zimbabwe (wheat production in 2014 was 251 128 tonnes). Comparatively, replacement of capture fisheries with farmed tilapia would require an equivalent 16 percent of current production in Zambia and Zimbabwe (tilapia production was 29 756 tonnes in 2015).

Water demand (Table 13-3)

Water demand within the basin would increase through replacement of capture fisheries with alternative food sources. Beef as a replacement would require the largest increase in water followed by chicken and pork. When compared to the agricultural water use from Zambia and Zimbabwe this equates to 1.5 percent, 0.7 percent and 0.3 percent of current water withdrawals (agricultural water use was 4.5 km^3 1998-2002). Crops would require less water, equivalent to 0.2 percent to 0.4 percent of the agricultural water withdrawals from Zambia and Zimbabwe.

Land requirement (Table 13-3)

Replacement of capture fisheries with beef would require the largest increase in land conversion, equivalent to 0.2 percent of the total pastureland area in Zambia and Zimbabwe (pastureland area was 3.21 million km^2 in 2014). Tilapia aquaculture would require an increase in land use, equivalent to 4.0 percent of the catchment area of the lake.

Greenhouse gas emissions (Table 13-3)

Estimated carbon emissions from 50 percent of Lake Kariba fisheries were 30 153 tonnes. The largest net increase would come from beef replacement, with additional emissions of 311 729 tonnes for beef, 19 424 tonnes for chicken, 1 440 tonnes for pork and 1 234 tonnes for farmed tilapia; the lowest emissions would come from crops (419 tonnes and 411 tonnes for rice and maize, respectively).

13.5 FISHERIES MANAGEMENT

National and regional management plans

Zimbabwe has specific legislation and governing bodies that regulate the inshore fishery, in contrast to Zambia where the access to the fishery is free. In Zimbabwe, the state controls the inshore fishery through the Department of National Parks and Wildlife Management, which limits access, closes fishing areas and restricts fishing gear. A permit system is in place whereby local authorities can issue fishing permits; a maximum of 2 530 nets is allowed on the Zimbabwean side of the lake. In Zambia access to the lake fishery is free on an open-access principle and fishers can fish anywhere. In general, there were no mesh restrictions until 1986 when minimum sizes for gillnets were introduced and beach seining was prohibited, however, there is little enforcement of regulations due to lack of resources (Kolding, Musando and Songore 2003).

To maintain and enhance the productivity of kapenta in Lake Kariba and ensure the fishery remains profitable, the Zambia and Zimbabwe Southern African Development Community project set a maximal limit of 500 kapenta rigs for the lake with 230 for Zambia and 270 for Zimbabwe (FAO, 2012).

Local management arrangements

In Zambia, attempts have been made to co-manage the Lake Kariba fishery between the State Department of Fisheries, local authorities and commercial kapenta producers. As part of the Zonal Management Committees, artisanal fishers were given the authority to control access to the lake and enforce regulations with the aim of reducing conflict and the number of foreign fishers. However, this was largely unsuccessful as stakeholders lost faith and resources to enforce regulations were lacking (Musumali *et al.,* 2009).

In Zimbabwe co-management of the inshore fishery has been relatively successful within the policy framework of the Communal Area Management Project For Indigenous Resources (CAMPFIRE). Within this framework, fishers receive proprietorship over inshore water resources and are empowered to manage fishery resources and develop and implement their own regulatory measures. As such, the Zimbabwean side of Lake Kariba management is apportioned between the state and rural districts (Pomeroy and Berkes, 1997).

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14 LIMPOPO RIVER

14.1 OVERVIEW

The Limpopo River (Table 14-1) flows for 1 750 km from the confluence of the Marcio and Crocodile River in South Africa to the Indian Ocean in Mozambique. From its source in the Limpopo Province of South Africa, the river flows north to form the border with Botswana where it arcs east and is joined by the Shashe River to form the border with Zimbabwe. From here, the river flows down the Great Escarpment (a major geological formation) and flows east into Mozambique and across the coastal plateau to the Indian Ocean. The river has 24 major tributaries, such as the Olifants, Mogalakwena and Mwenezi rivers (LRAK, 2017). The river's hydrology is characterized by flash flows in the headwaters and highly seasonal flows owing to climatic conditions. The mean dry season flows are as low as 20 m^3/s (September to October) and higher than 590 m^3/s at peak flows in February. The river basin is prone to flooding, with flows during peaks floods averaging about 1 600 m^3/s, with severe floods reaching over 17 750 m^3/s during which water levels rise from 0.5 m to 13 m during severe floods (World Meteorological Organization, 2012).

Table 14-1. Characteristics of the Limpopo River Basin

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
South Africa	182 843	44	15 355 482	84
Mozambique	84 534	21	1 095 253	13
Botswana	81 431	20	1 215 155	15
Zimbabwe	62 753	15	1 041 725	17
Total	**411 560**	**100**	**18 707 616**	**32**

Fish diversity

There are 66 fish species in the Limpopo River and one endemic species (*Marcusenius krameri*) (FishBase, 2017). This estimate differs from van der Mheen (1997) who stated there were 83 species.

Fish introductions

There are four exotic species which consist of three-spotted tilapia (*Oreochromis andersonii*) longfin tilapia (*Oreochromis macrochir*), nembwe (*Serranochromis jallae*) and smallmouth yellowfish (*Labeobarbus aeneus*) (FishBase, 2017). Van der Mheen (1997) however indicated that there were 18 exotic species such as: brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), mosquitofish (*Gambusia affinis*), common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*) and Nile tilapia (*Oreochromis niloticus*).

14.2 FISHERIES OVERVIEW

The Limpopo River has fewer fish species compared with other rivers in Africa (FAO, 2004), which is due to prolonged dry periods that characterize the region. These fluctuations impact the stream flow and water temperature making challenging environments for sustaining fish populations. More fish species are found in the tributaries, dams and streams that flow all year round. Cyprinids, catfish, tilapia, trout and several brackishwater species are the main species which provide a source of income and food to the people of the basin. The lower zone of the Limpopo River system is important in Mozambique as its flows contribute towards the productivity of the coastal brackishwater area, where fish production is significant. The contribution of the fisheries of the Limpopo to the economy and nutrition of the people of Botswana and Zimbabwe is very small (FAO, 2004). But in Botswana, commercial fishing is carried out on reservoirs and constitutes about 20 percent of the national production. The principal species harvested from these areas are *Labeo lunatus* in the Shashe Dam (Shashe River), bream species and *Oreochromis mossambicus* in the Gaborone Dam (Ngotwane River) and Lestobogo Dam (Motloutse River), and catfish in the Bokka Dam (Ngotwane River) (FAO, 2007b).

Fishing methods

In Mozambique artisanal fishers use non-motorized fishing vessels (usually boats 3 m to 8 m long). These fishers use beach seine, gillnet and longlines to catch fish (FAO, 2007a). In Botswana, commercial fishers use gillnets, while subsistence fishers use gear ranging from homemade gillnets, to fishing baskets, hook and line, fishing traps and fishing fences. Subsistence fishers who use traditional gear generally do not use or own any form of water transport which is normally cost prohibitive (FAO, 2007b).

Fish trade

No economic study of fisheries in the basin has been carried out. In Botswana, fish caught is consumed at the household level or sold at both formal and informal markets. Some fish such as catfish and tigerfish are bartered for other commodities such as grain (FAO, 2007b). In Mozambique, lack of cold storage facilities forces people to use traditional methods of processing, such as smoking, sun-drying and salt-drying (FAO, 2007a).

Employment

Participation in fisheries activities in the Limpopo River Basin is not known, but estimates for fisheries participation in the riparian countries are available. In Mozambique, an estimated 20 000 people are involved in the freshwater fishery sector, of which an estimated 696 people are women (FAO, 2007a). In Botswana, an estimated 13 000 men and 1 830 women are involved in freshwater fisheries activities, and in South Africa and estimated 62 272 men and 1 627 women are involved in fisheries activities. Participation in fishing activities in Zimbabwe is considerably higher compared to the other riparian countries, as the major inland fishing areas are on Lake Kariba and the Zambezi River.

Estimated fisheries production

Table 14-2 indicates the estimated fisheries production for the Limpopo River based on reservoir fisheries on its tributaries. No fishery estimates for South Africa, Mozambique and Zimbabwe were obtained. The fish catches from Table 14-2 consist of bream, catfish, silver catfish, carp and *Labeo* spp., with the most abundant species being bream and catfish.

The catch in Table 14-2 only reflects catches from gillnets, as currently there are no catch statistics available from other production sectors in Botswana. Other than the four main reservoirs (Table 14-2), a substantial amount of fishing goes unreported in other small dams within the basin. Therefore, these catch statistics are not representative of the actual production levels from the fishery (FAO, 2007b). As there are no historical catch data for this river it is not possible to evaluate catch trends.

Table 14-2. Estimated fisheries production for the Limpopo River

Country/waterbody		Catch estimate (tonnes)	Year	Reference
Botswana	Gaborone Dam	4 632.80	2004/2005	FAO (2007b)
	Bokaa Dam	8 545.40		
	Shashe Dam	13 331.30		
	Lestobogo Dam	4 500.80		
Total		**31 010.3**		

Aquaculture

In Mozambique, the Massingir Reservoir (Olifants River) offers considerable development opportunities for aquaculture. Freshwater aquaculture is dominated by farming of native cichlids and Mozambique tilapia, African catfish and carp. Annual production in the Massingir Reservoir is estimated to be more than 500 tonnes (FAO, 2007a). Conversely, in Botswana aquaculture is still at an early stage of development, probably due to the high capital costs involved (FAO, 2007b). Also, in South Africa freshwater fish culture is limited due to the supply of suitable water (FAO, 2010).

Recreational fisheries

Some recreational fishing has been observed in several small dams in Botswana, but the scale of recreational fisheries and the main target species are unknown. In Zimbabwe, sport fishing is hugely popular especially in the dams on the tributaries of the Limpopo River. The main target species in Zimbabwe are largemouth bass, *Oreochromis mossambicus, Labeo altivelis, Mormyyrops anguilloides* and tigerfish (*Hydrocynus vitattus*). Rod and line are the dominant gear used in Zimbabwe and Botswana (FAO, 2007b; FAO, 2016).

14.3 THREATS TO THE FISHERIES

Climate change

Long-term climate trends observed by the IPCC indicate that average temperatures across Africa are increasing, with an average increase of 0.7 °C over the last 100 years. The greatest temperature changes are predicted to take place in central Africa and would impact the Limpopo River Basin (UNEP, 2002). Different climate models have different predictions regarding the impact of climate change in the Limpopo River Basin. Based on a high emissions' scenario for the Limpopo River, precipitation levels are predicted to decline 24.20 percent in Botswana, 23.50 percent in Zimbabwe, 19 percent in South Africa and 19.50 percent in Mozambique, and declines in runoff are predicted (Zhu and Ringler, 2012). However, the impacts of climate change on fisheries have yet to be documented.

Invasive species

Nile tilapia (*O. niloticus*) has been widely introduced into Southern Africa for aquaculture, and escapees have become established in most river catchments within the subregion (Weyl, 2008). Escapee populations have been implicated in causing detrimental effects in the recipient rivers through decreased indigenous fish abundance and even localized extinction of indigenous populations (D'Amato *et al.,* 2007). The range of *O. niloticus* has expanded to include the Limpopo River, where it is spreading. This poses a concern for Mozambique tilapia (*O. mossambicus*) that is likely to be eradicated from the river system through hybridization, competition for habitat and trophic overlap with *O. niloticus* (Cambray and Swartz, 2007). The impact of *O. niloticus* on indigenous fish communities in the Limpopo River system may be especially severe in tributaries impacted by anthropogenic activities such as dam construction that generate pollution, siltation and habitat destruction (Skelton, 1990). Zengeya *et al.* (2013) found that 92 of 290 (32 percent) of river sections in the Limpopo Basin were at high risk of adverse impacts on indigenous riverine species from *O. niloticus* invasion. Zengeya *et al.* (2013) concluded that *O. niloticus* poses an unacceptable risk to indigenous fish species in the Limpopo River system, but the lack of up-to-date and accurate species occurrence records is a major limitation to assessing ecological risks.

Water quality

The Olifants River has been systematically impacted by acidification, industrial and agricultural chemicals, as well as organic pollutants and is one of the most polluted river systems in South Africa (Ashton and Dabrowski, 2011). Acid mine drainage and dumps in the Upper Olifants River are resulting in the acidification of streams and mobilization of metals from the sediment (McCarthy, 2011). Addo-Bediako *et al.* (2014) identified that the concentrations of lead, antimony and chromium in *O. mossambicus* tissues exceeded acceptable levels for safe consumption, and that levels of vanadium, cobalt, arsenic and manganese were also high in *O. mossambicus* caught from reservoirs in the Olifants River. The elevated metal pollution of important food fish poses a risk to human health (Addo-Bediako *et al.,* 2014).

14.4 EQUIVALENT FOOD REPLACEMENT

Given the relatively unknown status of the fisheries of the Limpopo River, the anthropogenic threats within the basin and that the climate of the basin makes dryland agriculture difficult (FAO, 2004), replacement estimates were based on a 50 percent reduction of the estimated fisheries catch (Table 14-2). Replacement food items are aquaculture (common carp and tilapia), livestock (beef, pork and chicken) and maize.

Table 14-3. Food production (tonnes), water (million m³), land (km²) and net increase in carbon emissions (thousand tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (thousand tonnes)
Tilapia	9 173 (76.5)	27.4 (0.2)	417 (0.1)	2.4
Beef	9 626 (0.8)	148.4 (1.1)	1 110 (0.07)	602.7
Pork	5 034 (1.3)	30.1 (0.2)	686 (0.04)	2.8
Chicken	15 855 (0.9)	68.6 (0.5)	425 (0.02)	37.6
Maize	20 373 (0.1)	24.9 (0.2)	36 (0.02)	0.8

Energy replacement (Table 14-3)

Aquaculture is not well developed in the Limpopo River Basin riparian countries. Replacement of kilojoules from capture fisheries with farmed tilapia would require the equivalent of 76.5 percent of current production (2015 farmed tilapia production was 11 993 tonnes). Tilapia aquaculture from Zimbabwe represented 87 percent of the riparian basin productivity; in the absence of this production, replacement tilapia production is equivalent to six times the current production (2015 tilapia production without Zimbabwe was 1 483 tonnes). Pork would require the smallest increase, equivalent to 1.3 percent of current production (2014 pork production was 388 363 tonnes). Maize production would require the largest production increase, equivalent to 0.1 percent of current production (2014 production was 17.09 million tonnes).

Water demand (Table 14-3)

Replacement of capture fisheries with beef would have the largest impact on water resources in the already water-scarce Limpopo River Basin. Beef production would require the equivalent of 1.1 percent of agricultural water use in the riparian countries (agricultural water use was 13.8 km³ 2015-2017). Maize, tilapia and pork would require similar amounts of water to replace capture, equivalent to 0.2 percent of agricultural water use in the riparian countries.

Land requirements (Table 14-3)

Farmed tilapia production would require land conversion, equivalent to 0.1 percent of the Limpopo River Basin area. As aquaculture is not well developed in the basin, an expansion in aquaculture activities and adoption of new technologies would see reduction in the amount of land required. Beef production would require the equivalent of 0.07 percent of the pastureland area in the riparian countries (2014 pastureland area was 1.7 million km²). Maize production would require 36 km² to replace capture fisheries, equivalent to 0.02 percent of arable land in the riparian countries (2014 arable land area was 225 490 km²).

Greenhouse gas emissions (Table 14-3)

Estimated carbon emissions from 50 percent loss to fisheries in the Limpopo River basin were 58 229 tonnes. Replacement of capture fisheries with alternative food sources would lead to a net increase in emissions, which would be highest for beef production (0.6 million tonnes), followed by chicken production (37 556 tonnes), pork production (2 784 tonnes), farmed tilapia (2 386 tonnes) and maize (810 tonnes).

14.5 FISHERIES MANAGEMENT

National management strategies

In Botswana, there are currently no fisheries regulations, possibly because there are no national fishery policies. The only fishery management legislation that exists is the Fish Protection Act, CAP 38: 05 of 1975. This act sets out illegal fishing methods (use of explosives, poisons and noxious substances), registration of fishers, designation of fishing areas and fishing seasons. Fishing in the four main reservoirs in the Limpopo River Basin in Botswana is controlled through effort limitation and fishing seasons. There are three commercial fishing licences at Gaborone Dam, two at Bokaa Dam, four at Shashe Dam and two at Letsibogo Dam. There is a closed season between October and January (FAO, 2007b).

In Mozambique, the legal basis of fisheries management falls under the Fisheries Law 3/90 of 26 September 1990. This stipulates total allowable catch quotas and limited entry regulation including licences, and also closed seasons and mesh size regulation (FAO, 2007a). But there are no specific fishing regulations for the Limpopo River Basin. There are no inland fishery management measures in South Africa; main fisheries management is for marine waters. In Zimbabwe, fisheries management is mainly based in the kapenta fishery on Lake Kariba, but the Zimbabwe Parks and Wildlife Management Authority is the regulatory and managerial body on which management of the entire fisheries of the country is based. Fishing regulations consist of regulating fish access (closed seasons and licenses) and allowable gear (FAO, 2016).

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15 OKAVANGO RIVER

15.1 OVERVIEW

The Okavango (Table 15-1) is the only major perennial river south of the equator in Africa that does not drain into the sea. Instead, the Okavango spreads onto the Kalahari Desert, where the river discharges 9.4 km^3 of water over 40 000 km^2 of sand, creating a wetland of global importance that is one of the largest Ramsar sites – the Okavango Delta. The Okavango River covers 370 000 km^2 and rises in Angola from two headwater rivers, the Cubango and the Cuito (Scudder, 2008). The river flows for a total length of 1 100 km (King and Chonguica, 2016). The Okavango has historic connections with the Zambezi River system when flooding backed up the Chobe River and into the upper portion of the delta. The Okavango is a flood pulse river, with a predictable flood season from December to June (King and Chonguica, 2016). The delta region covers a permanent area of 8 000 km^2 to 15 000 km^2 (Turton, Ashton and Cloete, 2003) and expands during the wet season to around 28 000 km^2 (Ramberg, Wolski and Krab, 2006). Approximately 95 percent of the runoff comes from Angola, 2.9 percent from Namibia and 2.6 percent from Botswana (Scudder, 2008). Most water is lost to the atmosphere through evapotranspiration (Giske, 1996), with 2 percent of the input appearing as output (Wilson and Dincer, 1976). The freshwater habitat of the river ranges from rapids and waterfalls in the Cubango River, shallow valleys in the Cuito River and floodplains and ox-bow lakes in the delta region (King and Chonguica, 2016).

Table 15-1. Characteristics of the Okavango River Basin

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
Angola	151 460	22		
Botswana	345 704	50		
Namibia	168 274	24		
Zimbabwe	25 670	4		
Total	**691 108**	**100**	**1 172 276**	**0.6**

Source: FAO (2014).

Fish diversity

According to FishBase there are 106 species in the Okavango River, with most species being Cyprinidae (26 species) followed by Cichlidae (23 species) (FishBase, 2017). There are also five endemic species which include *Zairichthys kavangoensis*, broadhead catfish (*Clariallabes platyprosopos*), Cubango kneria (*Parakneria fortiuta*), *Petrocephalus magnitrunci*, *P. simus* and one introduced species – *Oreochromis mossambicus* (FishBase, 2017). However, Tweddle *et al.* (2003) estimated that there were 71 species in the Okavango Delta. Permanent swamps are characterized by a high abundance of tigerfish (*Hydrocynus vittatus*), sharptooth catfish (*Clarias gariepinus*) and three-spot tilapia (*O. andersonii*), while seasonal swamps are dominated by silver catfish (*Schilbe intermedius*) and African pike (*Hepsetus odoe*) (Merron and Bruton, 1995).

Fish introductions

According to FishBase only Mozambique tilapia (*O. mossambicus*) has been introduced into the Okavango (Froese and Pauly, 2018).

15.2 FISHERIES OVERVIEW

The delta has commercial, subsistence and recreational fisheries (Mosepele and Kolding 2003). The commercial fishery is widely dispersed over the delta. The commercial species consist of three-spot tilapia (*O. andersoni*), red-breast tilapia (*Tilapia rendalli*), green-head tilapia (*O. macrochir*), sharp-tooth catfish (*C. gariepinus*), blunt-tooth catfish (*C. ngamensis*) and tigerfish (*Hydrocynus vittatus*) (Mosepele *et al.,* 2009). Generally, the higher magnitude and longer the duration of the flood leads to greater overall production of fish (Shipton, 2011), but fish availability and catchability is highest during low floods where fish are concentrated (Mosepele *et al.,* 2009). In commercial fisheries, generally there are cultural taboos associated with the consumption of *Clarias* spp. and tigerfish, resulting in low demand for these species, whereas *Tilapia* spp. are the preferred catch (Shipton, 2011). The subsistence fishery is a multispecies fishery with many target species, the principal species overall by weight being *O. andersonii* and *Tilapia rendalli*, while the banded tilapia (*Tilapia sparmanni*) was the most important species in the basket fishery, and Johnston's topminnow (*Aplocheilichthys johnstoni*) was the most important species in the mosquito net fishery (Shipton, 2011). The recreational fishery is mostly conducted in the upper delta in the Panhandle and lagoons (Mospele *et al.,* 2009). The recreational fishery primarily targets tigerfish (*H. vittatus*) and the larger breams (*Serranochromis robustus, O. andersonii* and *T. rendalli*) (Shipton, 2011).

Fishing methods

Hook and line, gillnets, baskets, spears and traps are the five principal fishing methods (Shipton, 2011). Subsistence fishery has also been known to use mosquito nets as small-meshed seine nets to harvest small species such as Johnston's topminnow (*A. johnstoni*) and spot-tailed barb (*Barbus afrovernayi*) (Mosepele, Mmopelwa and Mosepele, 2003). The commercial fishery primarily uses more modern methods such as gillnets, and hook and line occasionally, and some fishers use powered fishing vessels. The recreational fishery mainly uses hook and line fishing techniques (Shipton, 2011).

Fish trade

During the early years of the commercial fishery the government in Botswana secured a market for fishers to trade dry salted fish that was distributed by the Food Resources Department. But following the collapse of the market for dry salted fish, the department established the market for frozen fresh fish, which remains (Shipton, 2011).

Employment

More than 50 percent of the population along the river is involved in the fishery. A frame survey in 2005 indicated a total of 2 703 fishers, of whom 97 percent (2 622) were subsistence fishers, with the remaining 85 fishers coming from the commercial fishery; 52 percent or 1 405 fishers were women (Bokhutlo, Kootsositse and Mosepele, 2007). The number of recreational fishers is unknown as fishing lodges are not required to inform the Fisheries Division of the number of recreational fishers that they take into the delta (Shipton, 2011). Frame survey records indicated that the total number of fishers diminished between 1997 and 2005 from 3 243 to 2 703, a 17 percent decline (Mosepele, 2001; Bokhutlo, Kootsositse and Mosepele, 2007). But at the same time, the number of commercial fishers doubled from 44 to 85, although this can be attributed to an expansion in the definition of commercial fishers to include any fisher catching fish solely for sale using any fishing method (Shipton, 2011). In Namibia, a frame survey of the Kavango River reported by Munwela (2010) stated that there were 1 065 fishers along the river. Subsistence fishing households are typically single-headed households, most being women who depend on the fishery for livelihoods, as only 38 percent of fishers own livestock and only 18 percent of households raise and sell crops (Mosepele and Ngwenya, 2006).

Estimated fisheries production

Table 15-2 indicates the estimated fisheries production from the Okavango based on CPUE data from Kgathi, Mmopela and Mosepele, (2005) and the total number of fishers from the 2005 frame survey (2 703 fishers). Based on the 2005 frame survey's indication that 97 percent of fishers were subsistence fishers, the subsistence catch between 1996 and 2005 ranged from 656 tonnes to 708 tonnes annually. These figures are higher than previous estimates from Mosepele (2001), who estimated that the fishery harvest was low at around 270 tonnes annually, equivalent to 102 kg/fisher/year. Catches from the recreational fishing sector are unknown. The only fishers who are required to submit catch data are those involved in fishing tournaments, nevertheless, it is reported that most sport fishers practise catch and release, therefore the impact of recreational fishing on fish resources is likely to be small (Shipton, 2011); these data have been described as inadequate for the purposes of stock assessment. This is also a mirror image of frame survey statistics in Namibia, which are not sufficiently comprehensive to allow a full statistical analysis of data recordings (Tweddle and Hay, 2013). As such, the estimated fisheries production in Table 15-2 is likely to be an underestimation, but not by a considerable amount.

Table 15-2. Estimated fisheries production of the Okavango Basin *per annum*, based on CPUE of 0.25–0.27 tonnes/fisher/year

Area	Catch estimate (tonnes)	Year	Reference
Botswana	676–730	1996–2005	Kgathi, Mmopela and Mosepele (2005)

Status of the fisheries: catch trends

Stability in CPUE data would suggest that there has been no significant decline in fish stock abundance, and that fish stocks are not being 'fished down' or overexploited (Mosepele and Kolding, 2003; Shipton, 2011). Kgathi, Mmopela and Mosepele (2005) demonstrated that CPUE had remained stable between 1996 and 2002. Mosepele *et al.* (2009) further stated that there had been no significant changes in species diversity, in the mean length of commercial species or the species composition of the fish assemblage of the delta. The dominance of low-intensity, multispecies and multigear fishery is one of the reasons that fish biomass and diversity have remained high in areas that are fished (Jul-Larsen *et al.,* 2003). Also participation in the fishery has declined 17 percent from historical estimates and the number of gillnets had decreased from 1 410 to 1 314 between 1997 and 2005, which would suggest that there has been a reduction in effort in this fishery (Bokhutlo, Kootsositse and Mosepele, 2007).

Aquaculture

At present there is no fish farming in the Okavango Delta, however, many fishing communities within the region would like to start. However, fish farming is an unlikely scenario along the Okavango River owing to difficulties in obtaining land and no government support or funding (Shipton, 2011). Also, there are concerns over the use of alien species for aquaculture. In Namibia and Botswana fish-farming practices use only indigenous species, but Angolan authorities have authorized the introduction of Nile tilapia (*O. niloticus*) for fish farming in Central Angola. There are concerns that introduction of Nile tilapia aquaculture could have serious implications for downstream biodiversity and fisheries in Namibia and Botswana (Shipton, 2011).

Recreational fishing

The most important species in the recreational fishery are tigerfish, nembwe, three-spot tilapia, deepcheek bream and thin-face largemouth. Relatively little research has been conducted to establish the scale of the recreational fishery, its catch trends and the impact the fishery may have on fish resources. Recreational permits are required to access the fishery and can be purchased either individually or by tourist fishing lodges. Under the Fish Protection Regulations (1998) in Botswana, recreational fishers are allowed to keep a maximum of five fish/day, but are not required to submit catch returns to the Fisheries Division (Shipton, 2011).

15.3 THREATS TO THE FISHERIES

Habitat modification

Conflicts facing the delta that affect fish and fisheries include groundwater extractions and livestock grazing. The expansion of the cattle industry is a growing concern because creating pasture for cattle is usually accomplished by burning seasonal swampland during the dry season (Heinl *et al.,* 2007). This results in increased siltation and has led to blocking of wetland channels (Darkoh and Mbaiwa, 2014), which blocks seasonal spawning and feeding grounds, ultimately leading to reduced fish production.

Water demand is increasing in the three developing countries in the catchment of the Okavango. Currently the total amount of water diverted from the Okavango River has been small relative to total inflow. However, future water impoundments and diversions could cause major changes to the Okavango Delta system. Water removal for mining activities is growing, especially as mining prospects around the delta have increased over the last ten years (Darkoh and Mbaiwa, 2014).

The proposed construction of a national water project in Namibia presents the first major potential diversion of water from the Okavango. There is also increasing conflict regarding use of water resources between Namibia and Botswana, in which Namibia has proposed two projects (diversion for irrigation and for hydroelectric power generation), which could lead to direct downstream effects on the Okavango in Botswana. Both projects have the potential to reduce water flow and siltation in downstream areas (Darkoh and Mbaiwa, 2014). Current water abstraction amounts to 0.25 percent of the water inflow into the delta, but upstream developments in Namibia and Angola could reduce the permanently flooded area by as much as 38 percent (Plantec Africa, 2012).

Climate change

The impact of climate change on Okavango River discharge is highly variable. Climate change models predict temperature changes of between 2.60 °C and 2.64 °C by 2080 (Andersson *et al.,* 2006). Simulated climate models predict an annual mean reduction in flow of 20 percent between 2050 and 2080, and 26 percent reduction by 2099 (Andersson *et al.,* 2006). Precipitation is predicted to decline by 14 percent by 2050, and evapotranspiration is predicted to increase by 17.3 percent (Folwell and Farqhuarson, 2006). Increases in temperature and evapotranspiration and reduction in precipitation and flow could reduce the permanently flooded area of the delta and diminish the area for fish production.

15.4 EQUIVALENT FOOD REPLACEMENT

Fish resources have a major impact on food security in the delta. Mosepele and Ngwenya (2006) established that 80 percent of the subsistence fisher households derived half of their subsistence from fish and about 15 percent relied entirely on fish resources. For most subsistence fishers there is no other livelihood option available as income derived from fishing is insufficient to invest in other capital goods; only 38 percent of fishers own livestock and very few sell agricultural products. Therefore, the loss of capture fisheries would have a severely detrimental impact on the fishing population of the delta.

Equivalent food replacement estimates were established for a 100 percent loss to capture fisheries based on the higher fishery production value in Table 15-2. Replacement food sources are livestock (beef, pork and chicken), farmed fish (tilapia) and maize.

Table 15-3. Food production (tonnes), water (million m^3), land (km^2) and net increase in carbon emissions (thousand tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m^3 (percentage of agricultural water use)	Land required to replace fisheries in km^2 (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (thousand tonnes)
Tilapia	396 (37.7)	1.2 (0.3)	18 (0.005)	0.10
Beef	415 (0.2)	6.4 (1.5)	48 (0.004)	26.04
Pork	217 (0.2)	1.3 (0.3)	30 (0.002)	0.12
Chicken	685 (1.3)	2.9 (0.7)	19 (0.002)	1.62
Maize	880 (0.05)	1.1 (0.3)	4 (0.000009)	0.04

Energy replacement (Table 15-3)

Maize production would require the largest increase in production to replace capture fisheries, but as maize production is high (2014 production was 1.8 million tonnes in the riparian countries), this value only represents 0.05 percent of current production. Farmed tilapia would require replacement value of 396 tonnes. But as fish-farming practices within the Okavango Basin countries are undeveloped, compared to current production this represents 38 percent of the limited aquaculture production (tilapia aquaculture in 2015 was 1 052 tonnes). Pork production would require the smallest increase in production, equivalent to 0.2 percent of current production (2014 production was 107 735 tonnes).

Water demand (Table 15-3)

Replacement of fisheries with beef production would have the largest impact on freshwater resources, with 6.4 million m^3 of water required, equivalent to 1.5 percent of the agricultural water withdrawals from the Okavango Basin countries (agricultural water use was 0.5 km^3 1998-2002). Pork, maize and farmed tilapia production would all require similar water demand to replace fisheries.

Land requirements (Table 15-3)

Beef production would require the largest conversion, equivalent to 0.004 percent of the pastureland within the riparian countries (pastureland area in 2014 was 1.2 million km^2). Farmed tilapia production would require land-use conversion, equivalent to 0.005 percent of the basin area of the Okavango River. Maize production would require 4 km^2 of land to replace capture fisheries, equivalent to less than 0.0001 percent of arable land currently under maize production within the riparian countries (arable land area in 2014 was 17.6 million km^2).

Greenhouse gas emissions (Table 15-3)

Estimated carbon emissions from capture fisheries in the Okavango River basin were 2 519 tonnes. Net increases in carbon emissions from replacement of fisheries with food sources were highest for beef (26 043 tonnes) followed by chicken (1 622 tonnes), pork (120 tonnes), farmed tilapia (103 tonnes) and maize (35 tonnes).

15.5 FISHERIES MANAGEMENT

National management strategies

In Botswana, fisheries are legislated under the outdated Fish Protection Act, 1975 and regulated under the Fish Protection Regulations, 2008. Prior to the Fisheries Regulations, 2008 the fisheries in Botswana were effectively unregulated. These regulations set out guidelines that require licences for commercial gillnet fishers, recreational fishers and recreational tournament operators. Subsistence fisheries do not require a licence. The regulations also prohibit certain fishing practices, stipulate closed seasons and require the collection of catch data. The fishery in essence is still open access, in terms of licences, as there are no restrictions on the number of fishers (Shipton, 2011).

In Namibia, the Kavango fisheries are managed through the Inland Fisheries Resources Act, 2003. The act regulates the issue of fishing licences, indicates permissible fishing methods and identifies catch limits; it also prohibits certain fishing methods and fishing of endangered species. Fishing regulations are enforced by fishing inspectors (Government of Namibia, 2003). In Namibia, the Mahango Core Area of Bwabwata National Park is a protected area where no fishing is permitted because fish stocks in this area are in near pristine condition (Shipton, 2011).

Transboundary management strategies

The Okavango River Basin Water Commission (OKACOM) was established in 1994 by Angola, Botswana and Namibia to promote a coordinated approach to the sustainable management of the Okavango River Basin. From a transboundary perspective, OKACOM can address transboundary issues. In conjunction with the United States Agency for International Development (USAID), OKACOM is currently in the process of developing a transboundary fisheries management plan. The plan aims to establish a joint management system to ensure the conservation and sustainable use of shared fish resources for the benefit of local communities.

The plan will provide the foundation for responsible co-management of shared fish stocks within the Okavango–Cubango River Basin. To achieve this will require securing information on the yield and harvesting patterns used by the subsistence and commercial fisheries, as well as biological and biodiversity data of fish populations in Angola, Botswana and Namibia. One of the prospective outcomes of this plan is the facilitation of greater participation of fishing communities on the management of fishery resources upon which they largely depend on for food security and income (Tweddle and Hay, 2013).

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16 RED RIVER

16.1 OVERVIEW

After the Mekong River, the Red River (also known as the Yuan River and the Song Hong) is the second largest river in Viet Nam (Table 16-1) and plays an important economic and cultural role in the lives of the Vietnamese people. The Red River originates from the mountainous area of Yunnan Province in the People's Republic of China, and flows for 1 200 km. The river flows through the People's Republic of China and seven Vietnamese provinces before emptying into the Gulf of Tonkin in the South China Sea (Dang *et al.,* 2010). Red laterite soils in the mountainous area are fundamental in giving the river its characteristic colour (Van Maren, 2007). The main tributaries of the Red River are the Da and Lo rivers. The Da River has its origins in Yunnan Province near the source of the Red River (Funabiki *et al.,* 2007) and the Luo River comes from the People's Republic of China (Dang *et al.,* 2010). The mean annual water discharge of the Red River is 3 500 m^3/s (Tran, Nguyen and Dang, 2007) and its historical sediment load (160 x 10^6 tonnes/year) previously held a global ranking of ninth highest, but more recent estimates would suggest a significant drop to 40 x 10^6 tonnes/year under present conditions (Le *et al.,* 2007). The mainstream of the Red River remains one of the only major rivers in Southeast Asia that has not been impounded for hydropower development. However, the Hoa Binh Reservoir on the Da River tributary is one of the largest and highest dams in Southeast Asia and provides about 40 percent of Viet Nam's electricity (Le *et al.,* 2007).

Table 16-1. Characteristics of the Red River Basin

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
People's Republic of China	74 715	45	7 342 831	98
Lao PDR	1 627	1	26 893	17
Viet Nam	88 259	54	29 515 289	334
Total	**164 603**	**100**	**36 885 014**	**149**

Fish diversity

Estimated fish diversity in the Red River is outlined in Table 16-2. It is dominated by Cyprinidae (38 species) (FishBase, 2017). There is one endemic fish species (*Discogobio brachyphysallidos*) (FishBase, 2017). Species restricted to the basin include *Schistura macrotaenia*, *Placocheilus caudofasciatus*, *Glyptothorax quadriocellatus* and *Discogobio brachyphysallidos* (Hales, 2015; FishBase, 2017). Only one species has been introduced into the Red River – the streaked prochilod (*Prochilodus lineatus*) (FishBase, 2017).

Table 16-2. Fish diversity in the Red River

River	Total diversity	Endemic species	Introduced species
Red River	74–180	1–16	1

Sources: Dudgeon (2011); Hales (2015); FishBase (2017).

16.2 FISHERIES OVERVIEW

Inland fisheries on the Red River are mainly concentrated in the delta region in Viet Nam, where fisheries on floodplains and rice fields are an important source of food nutrition and seasonal income for rural communities. General information on fisheries within the Red River is limited but they are most likely typical of other monsoonal rivers in the area (e.g. the Mekong). Historically, freshwater capture fisheries were important for the economy and fishing cooperatives had annual production of several thousand tonnes. However, overexploitation has led to a reduction in fish resources and the end of most fishing cooperatives (FAO, 2005). Most capture fishery activities are conducted on a subsistence basis and remain important for rural communities. There are substantial areas of seasonal swamps within the basin that are utilized for fish production in the wet season and rice production in the dry season. The Red River Delta is characterized by an abundance of water and small family-sized ponds, which cover an area of 1 457 km^2 of which 20.3 percent is utilized for fish production, mainly to meet subsistence needs (Tran and Demaine, 1996). Fish species caught for subsistence use are unknown, but grass carp, bighead carp and Indian major carp are widely use in pond culture (Tran and Demaine, 1996).

Fishing methods

Fishing within the delta region is conducted using simple and sophisticated gear. Gillnets, longlines, lift-nets, push-nets and traps are the most popular gear. Gear use is largely unregulated and, as a result, the delta aquatic resources have been increasingly overexploited or destroyed (FAO, 2005; World Bank, 2005).

Fish trade

There is no specific information on fish marketing or trade from fisheries within the Red River. Most fish produced in ponds are destined for homestead use, whereas almost all of the processed aquaculture production is destined for export (FAO, 2005).

Employment

There are no specific estimates of fisher participation in Red River fisheries but the number of fishers from the proportional area of Yunnan Province that the Red River occupies in the People's Republic of China was 8 712 in 2013 (China Agriculture Yearbook, 2014). In Viet Nam, around 10 percent of the total population derives its main income directly or indirectly from fisheries (FAO, 2005). This does not include people who conduct fishing as part of a subsistence livelihood (likely to be substantial).

Estimated fisheries production

Table 16-3 indicates the estimated capture fisheries production from the Chinese and Vietnamese provinces that the main stem of the Red River flows through. The fishery catch from China represents the catch from the proportional area that the basin occupies within the province (Zhao and Shen, 2016). Fishery production in Thái Binh and Nam Đinh provinces, however, could also include marine catch as these provinces are on the coast and official fisheries statistics do not distinguish between marine and freshwater catches, nor do they show a breakdown of catch into species. Also, inland capture fishery statistics include culture-based capture, which includes stocked fish caught in lakes, reservoirs or other inland waters. As such, the figures in Table 16-3 do not represent freshwater capture fisheries only and are likely an overestimation of the catch.

Table 16-3. Estimated capture fisheries production for the Red River by province in China and Viet Nam

Country	Province/area	Catch estimate (tonnes)	Year	Reference
People's Republic of China	Yunnan	8 213	2015	Zhao and Shen (2016)
Viet Nam	Láo Cai	8	2014	General Statistics Office of Vietnam (2017)
	Yên Bái	793		
	Phú Tho	749		
	Hanoi	3 995		
	Vính Phúc	2 011		
	Hung Yên	757		
	Hà Nam	670		
	Thái Binh	58 683		
	Nam Đinh	44 208		
	Red River Delta	231 587		
Total		**351 674**		

Additionally, alternative estimates of fishery production from Norman-López and Innes (2008) suggested annual catches of 6 000 tonnes from the Red River system and a further 136 000 tonnes from the Red River Delta, however these estimates are from the 1980s and therefore not a reflection of current production.

Status of the fisheries: catch trends

According to FAO, the Red River was once described as being highly productive but it is now almost devoid of fish due to extensive flood control and the closure of floodplain fish breeding and nursery areas. Generally, fish catches from the coastal provinces on the Red River have been steadily increasing since 2000, from 21 166 tonnes to 58 683 tonnes in 2014 in Thai Binh for example, and likewise for Nam Dinh catches increased from 36 193 tonnes in 2000 to 44 208 tonnes in 2014. This is in contrast to the inland provinces where fish catches have fluctuated greatly and are showing a downward trend. For instance, fish catches in Phu Tho Province declined from 4 519 tonnes in 2000 to 749 tonnes in 2014, an 83 percent reduction. Similarly, fish catches in Ha Nam have declined from peak catches of 1 397 tonnes in 2008 to 670 tonnes in 2014. Fish catches in Yen Bai Province showed slow increases up to 2011, but subsequently catches have gradually declined (GSO, 2017).

Aquaculture

Fish farming in the Red River Delta is dominated by small-scale household-level integrated garden systems commonly known as VAC (*vuon* – garden, *ao* –pond and *chuong* – livestock quarters). Widely encouraged to improve household food security, fish farming within the Red River expanded from 13 000 tonnes in 1990 to 76 400 tonnes in 2003 and has continued to increase. Table 16-4 indicates the estimated fish aquaculture production from the provinces that the main stem of the Red River flows through. Again, the estimates from the coastal provinces and the delta could be overestimated through inclusion of marine aquaculture statistics.

Table 16-4. Estimated farmed fisheries production for the Red River by province in China and Viet Nam

Country	Province/area	Catch estimate (tonnes)	Year	Reference
People's Republic of China	Yunnan	289 892	2013	China Agriculture Yearbook (2015)
Viet Nam	Láo Cai	4 688	2014	GSO (2017)
	Yên Bái	5 621		
	Phú Tho	25 350		
	Hanoi	79 295		
	Vính Phúc	17 183		
	Hung Yên	30 186		
	Hà Nam	21 080		
	Thái Binh	38 673		
	Nam Đinh	35 981		
	Red River Delta	389 358		
Total		**937 307**		

Due to land-use pressures, increased aquaculture production in the Red River Delta has mainly been the product of an increase in intensity from 0.60 tonnes/ha/year to 2.10 tonnes/ha/year. Freshwater carp (Chinese and Indian major carp) dominates aquaculture production in the region. Current aquaculture practices seek to adopt other methods of production such as polyculture with smaller fish species and integrated rice–fish culture (Tran and Demaine, 1996). In addition, culture of ornamental fish appears to be a growing business for both the domestic and international markets (FAO, 2005).

16.3 THREATS TO THE FISHERIES

Habitat modification

Information regarding impacts that negatively affect fisheries within the Red River is not well known or documented. However, the presence of two large dams on the Da and Lo rivers is likely to have a significant impact on fish populations within the river. These dams prevent fish species migrating to spawning tributaries and completing their natural life cycles. The change from a lotic to a still lentic system will impact species that inhabit fast-flowing systems and impact any fish populations that rely on flow changes as migration cues (Baran, 2006). The construction of dams in the upper reaches has decreased the sediment load to the Red River by 70 percent, from pre-1980 levels between 1 060 and 640 tonnes/km^2/year to 280 tonnes/km^2/year in 2006. Further hydropower construction of two other planned dams within the basin will further reduce the sediment load by 20 percent (Le *et al.,* 2006). This reduction in sediment load to the river will alter nutrient dynamics and other biochemical processes and will likely lead to a reduction in overall productivity (Sarkkula *et al.,* 2010).

Climate change

Specific climate modelling for the Red River has not been conducted, but climate predictions for Viet Nam indicate mean annual temperature increases of 1 °C by 2050 and a 100 percent increase in the number of heatwaves and consequential increase in drought occurrence. Changes in rainfall frequency are expected to be concentrated in the rainy season, leading to an increase in intensity, frequency and duration of floods, and runoff is expected to increase by 7 percent. Of increasing concern is the impact of saltwater intrusion from sea-level rise, which in the Red River Delta, is predicted to rise by around 28 cm to 33 cm by 2050. This would have a detrimental impact on freshwater fisheries within the delta and possibly force a relocation of freshwater aquaculture farms (World Bank, 2011). However, the impacts of climate change may not be wholly detrimental – an increase in water flow and duration of flooding could increase fish productivity in some parts of the basin.

16.4 EQUIVALENT FOOD REPLACEMENT

Freshwater fish consumption in Viet Nam is high, with a contribution of 12.95 kg/capita/year in 2013. Fishing for subsistence purposes is especially important for rural communities that conduct fishing as a complementary occupation to rice farming. Increasing land pressures within the country mean that expansion into other forms of livestock production may not be feasible and consequently there is a high dependence on fish for food security. Therefore, food replacement estimates were established for a 50 percent reduction in capture fishery production from Table 16-4.

Table 16-5. Food production (tonnes), water (km^3), land (km^2) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km^3 (percentage of agricultural water use)	Land required to replace fisheries in km^2 (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Pangasius catfish	176 413 (15.0)	0.22 (0.3)	56 (0.03)	0.45
Common carp	103 772 (110.1)	0.32 (0.4)	17 295 (10.5)	
Tilapia	101 599 (35.9)	0.31 (0.4)	4 618 (2.8)	0.03
Beef	106 623 (36.4)	1.64 (2.1)	12 302 (191.6)	6.67
Pork	55 762 (1.8)	0.33 (0.4)	7 604 (118.4)	0.03
Chicken	175 615 (27.7)	0.76 (1.0)	4 712 (73.4)	0.41
Rice	149 723 (0.3)	0.33 (0.4)	327 (0.5)	0.02

Food replacement sources consist of livestock (beef, pork and chicken), aquaculture (Pangasius catfish, common carp and tilapia) and rice. Due to the very small area of the Red River that is present in Lao PDR and the low catch in the People's Republic of China, these countries are excluded from the replacement discussion.

Energy replacement (Table 16-5)

Increased aquaculture production increase to replace kilojoules from lost capture fisheries would be greatest for Pangasius catfish (176 413 tonnes). Common carp production would have to increase by 103 772 tonnes to replace capture fisheries, equivalent to 110 percent of current carp production (production in 2015 was 94 273 tonnes). Beef production would require a similar increase in production to tilapia, equivalent to 35.9 percent and 36.4 percent of current production in Viet Nam (beef production in 2014 was 292 501 tonnes). Chicken production would require an increase in production, equivalent to 27.7 percent from Viet Nam (chicken production in 2014 was 633 334 tonnes).

Water demand (Table 16-5)

Beef as replacement food would require the largest water use of 1.64 km^3, equivalent to 2.1 percent of the agricultural water use in Viet Nam (agricultural water use in Viet Nam was 77.8 km^3 in 2005). The remaining food sources require similar amounts of water to replace fisheries ranging from 0.22 km^3 to 0.33 km^3 which is equivalent 0.3 percent to 0.4 percent of the agricultural water use in Viet Nam.

Land requirements (Table 16-5)

Pangasius catfish for aquaculture requires the smallest land conversion, equivalent to 0.03 percent of the water basin area of the Red River. It is possible with increase in the efficiency of aquaculture practices that the land area required to farm common carp and tilapia could be reduced. Beef production would require the equivalent of 192 percent of the pastureland area in Viet Nam (pastureland area in 2014 was 6 883 km^2). Pork replacement would require land expansion equivalent to 118 percent of the pastureland area in Viet Nam.

Greenhouse gas emissions (Table 16-5)

Estimated carbon emissions from 50 percent of capture fisheries production from the Red River were 709 793 tonnes. Net increase in emissions would be greatest through replacement of fisheries by beef production (6.67 million tonnes), followed by Pangasius catfish (0.45 million tonnes), chicken (0.41 million tonnes), pork (0.03 million tonnes) farmed tilapia (0.03 million tonnes) and rice (0.02 million tonnes).

16.5 MANAGEMENT

National management strategies

In Viet Nam, fisheries are governed by the Fisheries Law, 2004, however this law mostly concerns the marine and coastal fishing sector and does not specifically apply to inland fisheries. On a provincial level, many provinces have departments of fisheries, which implement state management over fisheries. As part of the Fisheries Law, they encourage conservation, protection, rehabilitation and development of fisheries resources, including permitted fishing methods, seasonal and size limits. In addition, the planning and management of inland protected areas is also covered in the Fisheries Law. In general, the law seeks to improve the sustainability and management of fisheries resources and promote economic effectiveness that does not compromise the protection and rehabilitation of fishery resources.

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17 MEKONG RIVER

17.1 OVERVIEW

The Mekong is the tenth largest river in the world. It flows for approximately 4 909 km through the People's Republic of China, Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam before emptying into the South China Sea (Table 17-1). The Mekong River Basin covers a wide range of diverse topography and drainage patterns. The Tibetan Plateau, Three Rivers Area and Lancang Basin form the Upper Mekong Basin. The Northern Highlands, Khorat Plateau, Tonlé Sap Basin and Mekong Delta make up the Lower Mekong Basin. In the Upper Mekong the river tributaries are small and in the Lower Mekong the Tonlé Sap Basin, the Se Kong, Se San and Sre Pok (the 3S basins) are the main tributaries. The Tonlé Sap Lake drains into the Mekong during the dry season, then reverses during the wet season. The Mekong Delta begins near Phnom Penh with the largest tributary, the Bassac River, and then splits into smaller tributaries known as the 'Nine Dragons' (MRC, 2017). The Mekong River has mean annual flow of approximately 475 km^3 ranking it eighth in the world (Botkosal, 2009). The river experiences an annual monsoon season between May and September (FAO, 2016). The flood season in the Mekong River Basin lasts from June to November and accounts for 80 percent to 90 percent of the total annual flow for the river.

Table 17-1. Characteristics of the Mekong River

Country	Area of the basin (km^2)	Percent area of the basin in countries	Population of the river basin	Population density/km^2
Lao PDR	202 000	25	6 332 227	31
Thailand	184 000	23	19 628 532	104
People's Republic of China	165 000	21	6 790 681	41
Cambodia	155 000	20	13 541 781	87
Viet Nam	65 000	8	18 946 713	287
Myanmar	24 000	3	634 088	29
Total	**795 000**	**100**	**65 874 025**	**96.5**

Source: FAO (2016).

Fish diversity

Estimated fish diversity in the Mekong River is outlined in Table 17-2. Cyprinidae (281 species) and Nemacheilidae (92 species) are the most abundant families and there are 24 endemic species (FishBase, 2017). The diversity of the basin is second only to the Amazon River. The high degree of biodiversity is largely due to the complexity of the Mekong's ecosystem, variation in geology, terrain, water flow and seasonal floods that create an almost unlimited variety of river habitats (Coates *et al.,* 2003).

Table 17-2. Fish diversity of the Mekong River

Total diversity	Endemic species	Introduced species
801–1 200	24	12–17

Sources: Coates et al. (2003); Coates et al. (2005); FishBase (2017).

Fish introductions

Seventeen species were identified as having been introduced into the Mekong Basin. Fish introductions in the Mekong River have mainly been for aquaculture purposes, but also for the ornamental fish trade and to control water quality. Carp are one of the commonly introduced species (Indian major carp, grass carp, common carp, bighead carp, silver carp and black carp). Tilapia species include red throat tilapia, Nile tilapia, red cheek tilapia and Mozambique tilapia (Welcomme and Vidthayanon, 2003). Other known introductions that have also become established include the coral trout, catfish (African catfish and Pangasius catfish) and the pacu (FishBase, 2017).

17.2 FISHERIES OVERVIEW

The fisheries of the Lower Mekong Basin (LMB) are considered to be the world's largest. The Mekong fisheries are characterized by a diversity of species and habitats, as well as a plethora of different gear and fishing activities (Welcomme, 2001). The Mekong fisheries are of particular importance for the millions of rural people for whom fishing is a secondary occupation that provides secondary income and food security (MRC, 2010). Fisheries vary greatly from region to region, depending on availability and access to markets. In areas of more abundant resources and greater human population (e.g. the Thai Mekong) larger, more commercial fisheries are also present, particularly on lakes and reservoirs. In the delta area of Viet Nam, which has the highest population density, the fishery is for both commercial and subsistence use. Much of the industrial and commercial fishery in the Mekong is based on exploitation of fish that migrate from flood season feeding grounds to dry season habitats. Mekong fisheries are dominated by individual small-scale fisheries for subsistence use. Survey results have shown that between 64 percent and 93 percent of rural households in the LMB are involved in fisheries, both for their own consumption and for sale (Coates *et al.,* 2005). Within the Mekong River system, the fisheries exploit many species; estimates indicate that approximately 1 200 fish species are commonly traded, but the bulk of the fishery is based on 10 to 20 species (Coates *et al.,* 2003; Coates *et al.,* 2005). Although small-scale fishing contributes most to the total catch, in the most productive areas commercial fishers take a disproportionate share (Sjorsley, 2000).

Fishing methods

At least 100 types of gear are commonly used by the Mekong River fisheries. These can be classified into 16 main groups such as hand capture, wounding gear, traps, gillnets, covering gear, luring devices, illegal methods and anaesthetic methods (Hortle, 2009). Gear use tends to be similar wherever habitats are similar; gear use also varies with the time of year and water level. Small-scale fishers typically fish in habitats that are accessible by foot or canoes, such as rice fields, small streams, rivers and canals (Pham and Guttman, 1999; Hortle and Suntornratana, 2008). Traditional gear, such as traps, is widespread throughout rice fields; in open waterbodies, small-scale fishers tend to use gillnets, cast nets and hook and line (Hortle, 2009). Commercial fisheries tend to use larger gear and motorized craft to fish larger bodies of water. Illegal gear use is still common as regulations are considered unenforceable in practice.

Fish trade

Recent first-sale prices and revised productivity estimates indicate fisheries in the LMB alone are currently worth about USD 17 billion/year (Nam *et al.,* 2015). Indeed, fisheries account for nearly 18 percent of Cambodia's GDP and contribute more towards the country's production than rice farming; in Lao PDR, the fisheries value is equivalent to 12.8 percent of the country's GDP (Nam *et al.,* 2015). Proportionally less important to the national economy in Thailand and Viet Nam, the Mekong fishery contributes over USD 750 million to the GDP annually (MRC, 2017). Most of the fish caught by small-scale subsistence fishers within the LMB serves a non-monetary purpose and is eaten directly or traded for other commodities (Lynch *et al.,* 2016). Export markets of Mekong fish are poorly documented and include unofficial taxes and fees. Generally, export of high-value species from Lao PDR to Thailand is generally unregulated and is considered inefficient compared to the domestic industry (Nam *et al.,* 2005).

Employment

Table 17-3 indicates employment in the Mekong River Basin fisheries. However, this does not reflect the involvement of part-time subsistence fishers who use fishing as part of a diversified livelihood strategy (Dixon *et al.,* 2003). Those who only fish seasonally do not appear in surveys as 'fishers' but may consider themselves as 'farmers' (Nam *et al.,* 2015). Separate studies have indicated that two-thirds of LMB households, more than 40 million people, are either dependent on or engaged in fisheries (World Bank, 2012). Therefore, the fishery participation estimates in Table 17-3 are likely to be grossly underestimated. Most households sell or barter some fish and full-time fishing is practised by fewer than 10 percent of households. Fishing is generally done by men and women are mostly involved in fish processing, marketing and gear-making. However, women mainly conduct small-scale homestead aquaculture as this tends to be classed as a 'household' activity (Hortle, 2009).

Table 17-3. Employment in Mekong River Basin fishing activities

Country	Fishers	Processing/trade	Fish farmers	Total
Cambodia	1 009 190	220 464	80 976	1 310 630
Lao PDR	526 000		782 800	1 308 800
Thailand	1 065 900		315 948	1 381 848
Viet Nam	689 910	133 705	279 550	1 103 165
People's Republic of China				
Total	**3 291 300**	**354 169**	**1 459 274**	**5 104 443**

Source: Nam *et al.* (2015).

Fisheries production estimates

There are several estimates for capture fisheries production in the Mekong River Basin. Table 17-4 outlines estimates for fish catches from the Mekong Basin countries based on consumption data from Hortle and Bamrungrach (2015) but given the age of these data the estimates are likely an underestimation. Between 1970 and 2000 published estimates for fishery production for the LMB have varied between 0.5 million tonnes and 3.1 million tonnes annually (Hortle, 2007). The Mekong River Commission estimated capture fisheries production of 1.9 million tonnes in 2008 (MRC, 2010). Official statistics are likely to be underestimated (Coates, 2002). Accurate catch data come from some well-defined areas (such as rice fields or reservoirs), but large-scale surveys are often unreliable because of the difficulty in covering the huge diversity of gear and fishers, and the likelihood that fishers routinely prevaricate about catches to avoid taxes (Hortle, 2009).

Fisheries data might be somewhat unreliable in Thailand as monitoring is only carried out on the reservoirs and small waterbodies. In Lao PDR, data collection is largely conducted under research projects. There is no sampling of or estimation of river fisheries, so this portion of fishery production is not likely included in fisheries statistics (Coates, 2002). Additionally, in Viet Nam, the Department of Fisheries finds it difficult to fulfil its mandate, due to the lack of professional management at the district level, which has resulted in limited monitoring and data collection and consequently unreliable data. Where fishery data are known to be collected, data are based on reported landings for commercially licensed gear only, with vague estimates for other parts of the fishery (Coates, 2002).

In Cambodia, registered fishers have no incentive to accurately report catches and most of the catch is caught by small-scale or subsistence fishers, which is difficult to quantify (Hortle, Lieng and Valbo-Jorgensen, 2004). Only fishery data from large- and medium-scale fisheries are systematically collected, thus the subsistence portion of the catch goes unrecorded. Data collection systems were reorganized after 2011, when the fishing 'lot' system was dismantled and the Department of Fisheries lost this source of data. Fishery statistics are still underestimated as there is no functioning statistical system outside of the reports from provincial offices, and there is no independent verification of fisheries data; moreover, no monitoring systems are in place. Essentially, most fishery statistics are based on estimates made in field offices and are not the result of information collection.

Fisheries statistics for Myanmar are inconsistent and considered overestimated by numerous sources. Original fisheries statistics came from fishing lots and when this system was disbanded (as in Cambodia) this source of data was lost. Actual fish catch is not measured for fishery statistics, but estimates are based on the number of licensed gears multiplied by the constant biomass per gear and per unit area. Also, as only 4 percent of the Mekong Basin lies in this country, in a mountainous area, it can be assumed that the share of the Mekong fishery in Myanmar is not significant (Baran, Jantunen and Chong, 2007).

Estimated fish catch from the proportional area of Yunnan Province in the People's Republic of China China was 8 808 tonnes based on data from Zhao and Shen (2016).

Table 17-4. Production estimates for the Mekong River

Country	Catch estimate (tonnes)	Year	Reference
Cambodia	767 000	2000	Hortle and Bamrungrach (2015)
People's Republic of China	8 808[1]	2015	Zhao and Shen (2016)
Lao PDR	246 000		
Thailand	921 000	2000	Hortle and Bamrungrach (2015)
Viet Nam	369 000		
Total	**2 311 808**		

[1] From Yunnan Province, People's Republic of China.

Aquaculture

Aquaculture is well developed in Thailand and a massive industry in the Mekong Delta in Viet Nam, where aquaculture may be contributing about half the total yield from the fishery. Aquaculture contributed 2.1 million tonnes to the Mekong fishery in 2012 and was worth an estimated USD 5.8 billion in 2015 (Nam *et al.,* 2015). The average annual growth rate has been around 17 percent, which is three times higher than the world average of 5.6 percent (OECD/FAO 2015). Viet Nam is by far the largest aquaculture producer, accounting for almost 90 percent of the basin production value, mainly from farming the striped catfish (*Pangassius hypothalamus*), tilapia and black tiger shrimp (Nam *et al.,* 2015).

Recreational fisheries

Many Mekong system fish are important in the aquarium trade, and recreational or sport fishing is becoming increasingly popular, especially in the more affluent areas, but published information on these kinds of fisheries is scant (Hortle, 2009).

17.3 THREATS TO THE FISHERIES

Climate change

In the LMB temperature increases are predicted to reach an average of 3 °C to 5 °C by the end of the century. Rates of change in temperature are highest in the 3S catchment of Eastern Cambodia and in the Mekong Delta of Viet Nam and Cambodia, where increases of 2 °C to 3 °C could be reached before 2050, and up to 5 °C by the end of the century (ICEM, 2013). Precipitation is projected to increase between 3 percent and 14 percent (35 mm to 365 mm) throughout the basin. Projections also indicate climate change will alter the Mekong hydrobiological seasons; this would include the wet season starting one to two weeks earlier and the dry season starting one to three weeks earlier. To some extent capture fisheries in the Mekong Basin are buffered against climate change by the extensive ecosystem biodiversity. Some species may benefit from changing conditions, possibly maintaining fisheries productivity, while other less adaptive species may decline. This is likely to lead to a decline in overall biodiversity (ICEM, 2013). Higher flows during the wet season could benefit fisheries, but changes to flows in response to temporal changes in precipitation could disrupt the movement of migrating species (MRC, 2010).

Hydropower and dam construction

Hydropower dams are considered the biggest threat to fisheries in the Mekong River Basin. There are currently 371 dams in operation or under construction along the Mekong and a further 98 dams are planned or proposed for the basin (Winemiller *et al.,* 2016). There are 31 dams in operation or under construction on the Mekong mainstream (Baran, Meynell and Kura, 2009; MRC, 2010; Schmutz and Mielach, 2015). In the Upper Mekong there are six dams; a further seven are in commission or under construction. In the Lower Mekong, 11 dams are planned of which seven are in Lao PDR, two on the Thai–Lao PDR border and two in Cambodia (ICEM, 2010).

The ecological effect of dams is mainly the loss of connectivity between natural environments; the physical presence of dams will block migration routes preventing fish from completing their natural life cycle. In an environment such as the Mekong where fish migrate each year between upstream and downstream habitats, dams located downstream near floodplain areas would have the largest impact on fisheries (Baran, Jantunen and Chong, 2007). Hydropower dams would also alter the river flow and change the habitat from lotic to a still lentic system (Pelicice, Pompeu and Agostinbo, 2015), which would impact most Mekong species as 90 percent of species with known migration triggers respond to water flow changes (Baran, 2006). Reduction in sediment trapping will alter the nutrient dynamics and other biogeochemical processes leading to a reduction in overall productivity (Sarkkula *et al.,* 2010). Indeed, attempts to offset the lost river fishery through reservoir fisheries will only replace about 10 percent of the capture fisheries as the impounded river cannot support the same species diversity as it did in the past (ICEM, 2010).

Modelled predictions indicate that basin-wide, the development of 77 dams in the Mekong would result in the loss of 550 000 tonnes to 880 000 tonnes of capture fisheries (ICEM, 2010; Lymer *et al.,* 2016), or 23 percent to 39 percent of the Mekong River Basin capture fisheries. Also, recent estimates of fish loss from the 11 main stem dams in Cambodia and Viet Nam indicate that fisheries yield would be reduced by 238 377 tonnes and 358 514 tonnes respectively, which is equivalent to 44 percent and 42 percent of the capture fisheries in each country (DHI HDR, 2017).

17.4 EQUIVALENT FOOD REPLACEMENT

Mekong fisheries contribute to the livelihoods of about 60 million people. Fisheries engage people in direct and indirect employment and provide food as well as food security. Today 60 million people (12 million households) live in the LMB and 80 percent rely directly on the river system for their food and livelihoods (Baran and Myschowoda, 2009; ICEM, 2010). Most of these households would be affected by alterations to fish availability, as fish is the main source of dietary protein (MRC, 2005). Fisheries supply 49 percent to 82 percent of the animal protein consumed in the LMB, and 90 percent of this comes from capture fisheries. Average per capita consumption in the LMB is estimated at 45.4 kg/capita/year.

Considering the importance of capture fisheries within the region, food replacement estimates were established for a 50 percent loss in the capture fishery, based on the basin total from Table 17-4. Food replacements consist of aquaculture (farmed tilapia, farmed common carp and farmed Pangasius catfish), livestock (beef, pork and chicken) and crops (maize and rice).

Table 17-5. Food production (tonnes), water (km³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Pangasius catfish	888 729 (75.4)	7.7 (5.4)	379 (0.05)	3.56
Tilapia	688 649 (148.4)	2.1 (1.6)	31 302 (3.9)	0.18
Common carp	703 379 (607.3)	2.2 (1.5)	117 229 (14.7)	
Beef	722 703 (130)	11.1 (7.9)	83 388 (230.5)	45.24
Pork	377,966	2.3 (1.6)	51 540 (142.5)	0.21
Chicken	1 190 334	5.1 (3.7)	31 941 (88.3)	2.81
Rice	1 011 785 (1.1)	2.3 (1.6)	2 218 (0.8)	0.12
Maize	1 529 442	1.9 (1.3)	5 511 (1.9)	0.06

Food replacement estimates were based on the LMB countries (Thailand, Viet Nam, Lao PDR and Cambodia); the People's Republic of China and Myanmar were excluded due to their small proportion in and catch from the basin.

Energy replacement (Table 17-5)

Aquaculture production would have to significantly increase to replace kilojoules from capture fisheries. Pangasius catfish production would have to increase 888 729 tonnes, equivalent to 75.4 percent of farmed Pangasius production in the LMB (2015 production was 1.2 million tonnes), most of which (96 percent) comes from Viet Nam. Replacement of kilojoules from capture fisheries with farmed common carp production would require the equivalent of 607.3 percent of the current production from LMB countries (2015 production was 115 829 tonnes). Tilapia production would have to nearly double to replace capture fisheries (2015 tilapia production was 463 929 tonnes). Beef production would have to increase by an equivalent of 130 percent of current beef production from LMB countries (2014 production was 555 101 million tonnes).

Water demand (Table 17-5)

Water resources would be severely impacted by the replacement of capture fisheries with alternative food sources. Beef as a replacement source would have the largest water demand, equivalent to 7.9 percent of the agricultural water use from LMB countries (total agricultural water use was 140.8 km^3 2003-2007). Tilapia production would require the smallest amount of water to replace capture fisheries, equivalent to 1.6 percent of the agricultural water use from LMB countries.

Land requirements (Table 17-5)

Land use under food production would have to increase to replace capture fisheries with alternative food sources. In terms of area, common carp production would require a large increase equivalent to 14.7 percent of the Mekong Basin area. Beef production would require the largest land-use conversion of any terrestrial protein source, equivalent to 230.5 percent of the pastureland area in LMB countries (2014 pastureland area was 36 170 km^2). Replacement of capture fisheries with pork production would require the equivalent of 142.5 percent of the pastureland area in LMB countries.

Greenhouse gas emissions (Table 17-5)

Carbon emissions from 50 percent of the Mekong capture fisheries were estimated at 4 376 640 tonnes. Replacement of capture fisheries with rice production would result in significant increases in carbon emissions. Additional carbon emissions from livestock would be higher than from aquaculture, particularly beef production (45.24 million tonnes).This value was significantly higher than additional emissions from aquaculture (3.56 million tonnes and 0.18 million tonnes from Pangasius catfish and tilapia aquaculture, respectively).

17.5 FISHERIES MANAGEMENT

Integrated planning approaches for large complex river basins can help ensure effective management and equitable use of water sources. The IWRM approach is the cornerstone of the MRC's approach to management basin-wide. Transboundary cooperation has been achieved through five bilateral projects, including a joint outreach project in Cambodia's Tonlé Sap Lake; a fishery management project in the Mekong and Sekong rivers of Cambodia and Lao PDR; wetland and floodplain management projects in Lao PDR and Thailand; and two water resource management projects within the Mekong Delta. The five projects were launched in 2013 and are undertaking baseline studies to identify common water resource management issues. The outputs of these projects will contribute to developing joint management plans to address issues at national and subnational levels.

Transboundary fisheries management on the Mekong and Sekong rivers in Cambodia and Lao PDR

The overall objective of this transboundary project is improved fisheries management in the bordering provinces of Stung Treng and Kratie in Cambodia and Champassak and Attapeu in Lao PDR (MRC, 2014). Some of the objectives of the project are:

- A functioning, joint fisheries-monitoring programme in Mekong and Sekong fisheries;
- Effective fisheries dialogue between Cambodia and Lao PDR through national workshops; and
- Transboundary cooperation in fisheries management through the creation of a fisheries transboundary management plan that is supported and promoted at the village level (MRC, 2014).

Co-management strategies

Community-based fisheries management and co-management have been implemented in various parts of the LMB, particularly in Khong District and Champasak Province of Lao PDR. Communities were permitted to choose what regulations to adopt based on local conditions, which were enforced by local governments, regulations included:

- Establishing conservation zones in deep water (10 m to 50 m) parts of the Mekong; these are essentially 'no take zones';
- Banning of specific gear use, including blocking of streams with fish traps at the start of the wet season to avoid the harvesting of fish making short migrations, spear fishing with lights at night, "water beating" fishing and catching of juvenile snakeheads; and
- Protection of inundated forest habitat (Baird, 2007).

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18 TONLÉ SAP LAKE

18.1 OVERVIEW

Tonlé Sap Lake in Cambodia is the largest freshwater lake in Southeast Asia. The dry season area of the permanent lake is approximately 2 500 km^2 expanding to as much as 15 000 km^2 in the wet season (MRC, 2003) (Table 18-1). The lake is relatively shallow with a maximum dry season depth of 3.3 m. The lake experiences a large hydrological change annually. During the dry season, the Tonlé Sap Lake drains into the Mekong River. However, this is reversed during the wet season when increased river discharge cannot be accommodated, and the flow of the Tonlé Sap River reverses direction as the water flows 'upstream' eventually contributing 50 percent of the maximum wet season water volume, which expands from 1.5 km^3 to between 60 km^3 and 70 km^3 (MRC, 2010).

Table 18-1. Characteristics of Tonlé Sap Lake

Area of the lake (km^2)	Percent area of the lake in Cambodia	Population of the river basin (2000)
Dry season: 2 500 Wet season: 15 000	100	1 250 000

Source: Hap, Seng and Chuenpagdee (2006).

Fish diversity

Due to the richness of fish fauna and lack of consensus among taxonomists working within the region, it is difficult to get a reliable estimate for the total number of species in the Tonlé Sap Basin. Estimates for the diversity of fish species in Tonlé Sap Lake are outlined in Table 18-2. The fish diversity reflects the connection between the lake and the Mekong River system. Most of the fish species recorded from the lake belong to four families: Cyprinidae (39 percent), Bagridae (8 percent), Siluridae (7 percent) and Pangasiidae (7 percent) (Campbell *et al.,* 2006).

Table 18-2. Fish diversity of Tonlé Sap Lake

Total species diversity	Endemic	Introduced
149–197	0	1

Sources: Campbell *et al.* (2006); FishBase (2017).

Fish introductions

Exotic species such as silver carp, common carp and tilapia that are commonly seen in some parts of the Mekong Basin have not established large populations in Tonlé Sap Lake. This may be due in part to the small-scale nature of aquaculture within Cambodia and the plentiful supply of capture fisheries. Also, fish culture is mainly based on indigenous species such as the giant snakehead and Pangasius catfish (Campbell *et al.,* 2006).

18.2 FISHERIES OVERVIEW

Inland fisheries contribute 90 percent of Cambodia's total fish catch (Sam, Lieng and Thor, 2003), of which Tonlé Sap Lake fisheries provide about 60 percent of the total inland catch (World Bank, 1995; Ojendal and Torell, 1998). Fishing is considered central to the lives of people of the Tonlé Sap Lake Basin (Hap, Seng and Chuenpagdee 2006). The fishery on the lake is intensive, highly organized and includes both small- and large-scale operations. Large-scale fishing is practised in areas where exclusive access and exploitation rights are acquired, but fishing is only practised between October and May. Open-access areas are shared between medium-scale fisheries and subsistence fisheries, for which medium-scale fisheries are subject to yearly licensing by the Department of Fisheries. Subsistence fishing is allowed throughout the year and in all fishing grounds; most of the fishing is done for subsistence by individuals or at the household level (Lamberts, 2001). The large-scale fisheries' focus is mainly on black fish (that can tolerate low dissolved oxygen concentrations) moving out of the floodplains. In the Tonlé Sap Lake fishery, the giant snakehead contributes most to the catch, while catches in the 'lot' fishery in the Tonlé Sap River are dominated by small migratory cyprinids (Van Zalinge *et al.,* 2000).

Fishing methods

Fishing gear and methods are usually specific to the type of fishery and location within the ecosystem. Large-scale fishing within the Tonlé Sap Lake is mainly conducted using seine nets. To prevent fish from escaping, extended bamboo systems are erected when floodwaters recede and fish are chased into fenced loading areas where the catch is loaded onto boats. This sort of fishing operation is non-selective and mainly targets migrating fish. Barrage fisheries are found at the delta between the Tonlé Sap River and lake. This method tends to catch fish live producing a high-quality market product (FAO, 2011). About 24 different forms of gear are used in the medium-scale fishery. The most common are large arrow-shaped traps, gillnets, encircling seines and longlines. Gillnets are the most common with 63 percent of households in fishing communities using them (Ahmed *et al.,* 1998). Small-scale fisheries are dominated by gillnets, with half of fishing households using them. There are also reports of widespread illegal fishing operations such as the use of explosives, electro-fishing, poisoning and fishing with illegally-sized meshes (Lamberts, 2001).

Fish trade

Fish catch is graded according to size and species. Grade 1 species, which are 1 kg or more in weight, fetch the highest prices, and are often transported to urban areas or exported. Grade 2 fish, which are between 0.5 kg and 1 kg, are usually consumed locally. Grade 3 fish weigh less than 0.5 kg and are processed into feed (Lamberts, 2001). The gross annual income for the 1.25 million people (2003 estimate) living by the Tonlé Sap Lake was estimated at USD 233 million; of this, home consumption of fisheries products was worth USD 13 million (Hap, Seng and Chuenpagdee, 2006).

Employment

There are varying estimates of the involvement in fishing activities; as for the majority, fishing is not conducted as a full-time occupation and is not listed in national population census. Previous studies in Cambodia have shown that 40 percent of the total population on the Tonlé Sap Lake Basin are dependent on the lake and its floodplains for their livelihoods. A 2008 census concluded that 64 percent of rural households (over 7 million people) around Tonlé Sap Lake were engaged in fishing (FAO, 2010). However, only 0.6 percent of the population declared fishing as a full-time occupation (Baran and Gallego, 2015).

Estimated fisheries production

Table 18-3 indicates the estimated fisheries production from Tonlé Sap Lake. Fisheries estimates of production ranged from 179 500 tonnes to 256 000 tonnes annually from 1995 to 2000, yielding 130 kg to 165 kg/ha (Lieng and Van Zalinge, 2001) or an average 2.4 kg/fisher/day (Ouch and Dubeau, 2004). Catch data were traditionally collected by provincial offices of the Department of Fisheries (DoF). Registered fishers have no incentive to accurately report catches and small-scale subsistence fisheries are difficult to quantify (Hortle, Lieng and Valbo-Jorgensen, 2004). Only data from the formally licensed fisheries (large- and medium-scale fisheries) are systematically collected, thus fish catches from subsistence fishing often go unrecorded.

The DoF attempted to account for subsistence fisheries by estimating additional productivity from subsistence fisheries, and even used consumption data from Mekong River Commission reports (Hortle, 2009) to estimate fish production. Unfortunately, data collection systems were reorganized after 2011, when the fishing 'lot' system was disbanded, and the DoF lost access to this source of data. Fishery catches are still underestimated as there is no functioning statistical system outside of the reports from provincial offices, and there is no independent verification of fisheries data and no monitoring systems are in place

(Lamberts, 2001). Essentially, most fishery statistics are based on estimates made in field offices and are not the result of information collection.

Table 18-3. Production estimates for Tonlé Sap Lake

Catch estimate (tonnes)	Year	Reference
246 000	2001	Lieng and Van Zalinge (2001)

Status of the fisheries: catch trends

Several researchers believe that the Tonlé Sap Lake fishery has been declining (Mak, 2000). However, there is also strong evidence that fish stocks have not declined overall but that catches are higher than at any time in the past (Van Zalinge *et al.,* 2001). The population of the basin has increased faster than the harvest. As a result, the CPUE is falling and large- and medium-size species are becoming rarer. The causes of perceived fishery decline stem from widespread illegal fishing and overfishing caused by an increasing number of fishers coupled with ineffective management (Baran, Starr and Kura, 2007).

Aquaculture

Aquaculture is a relatively minor component of the total fisheries production in Cambodia, accounting for less than 9.7 percent of total fish production, but expanded to roughly 35 000 tonnes in 2007 (MRC, 2010). In the Tonlé Sap ecosystem, aquaculture is only practised in cages and pens, and originally originated from stocking of surplus fish caught during the peak fishing season. Most species used for aquaculture are indigenous, mainly Pangasius catfish and giant snakehead (Lamberts, 2001).

18.3 THREAT TO THE FISHERIES

Climate change

Tonlé Sap Lake is expected to be particularly sensitive to climate change, as changes to river flow could alter the area's unique flood pulse system and influence the productivity of the lake and associated floodplains. Minimum water levels are predicted to increase by an average of 0.1 m with a maximum of 2.3 m (Eastham *et al.,* 2008). The impact is likely to be complex, with potential positive and negative effects. Projected increases in the lake's minimum area could inundate the flooded forests, which are only submerged during the wet season, and destroy these habitats. This would be detrimental to fish stocks, as the forest protects the floodplain against erosion and provides a breeding and shelter habitat (Baran, Starr and Kura, 2007). In addition, predicted increases in temperature (estimated 2 °C to 3 °C) will likely lead to warmer water and increased degradation of organic matter generating oxygen depletion on the lakebed. On the other hand, larger flood volumes have so far been associated with an increase in capture fisheries on Tonlé Sap Lake. Increased runoff will likely influence the amount of sediment and nutrient cycling in the lake (Eastham *et al.,* 2008). A combination of increase in temperature and nutrients could increase growth rates and stimulate ecosystem production of the lake (MRC, 2010).

Overfishing

Total catch is believed to have increased between 1940 and 1990, although catch/fisher has declined (Van Zalinge *et al.,* 2001). A degree of fishing down has taken place since the 1930s, which is not surprising given the increasing population and gear use, which have led to increasing fishing pressure. During this time, the contribution of large fish species to the catch has decreased and many of the largest species are now rare. In additional the average size of smaller fish has declined (Hortle, Lieng and Valbo-Jorgensen, 2004), which is often seen as an indication of overfishing. However, low water levels have also been attributed as a cause of declines in fish catch, as in 2003 low water levels caused the fish catch to decrease by as much as 50 percent (Starr, 2004).

Habitat modification

The onset of the flood season varies significantly depending on the timing of floods in the Mekong River Basin. Hydropower development within the Mekong River Basin could impact Tonlé Sap Lake through alteration of the wet season flood pulses. Kummu and Sarkkula (2008) found that hydropower projects on the Mekong mainstream would increase the dry season water level between 0.15 m and 0.6 m, which would result in an increase of the permanent lake area of 400 km^2 to 1 000 km^2.

Hydropower development would also significantly reduce the sediment and nutrients entering the lake. Most sediment in the Lower Mekong Basin comes from the rapidly eroding Lancang region and the Tibetan Plateau. Kondolf, Rubin and Minear (2014) found that if all proposed dams for the Mekong River were constructed without sufficient sediment management measures, the sediment load in Tonlé Sap Lake would be reduced by 96 percent. A reduction in sediment load would have a profound impact on fisheries and reduce the natural nutrient cycle flowing into the lake, threatening the productivity of the system (Sarkkula *et al.,* 2010).

18.4 EQUIVALENT FOOD REPLACEMENT

Changes in aquatic productivity of the lake would directly affect food security as almost all villagers rely on fishing for their livelihoods and food. Freshwater fish provides the main source of protein and for fishing communities living within the Tonlé Sap Lake consumption rates are more than 70 kg/capita/year (So, 2010). Cambodia is one of the world's poorest countries; limited opportunities for income and low wages mean household purchasing power and food security are low. In addition, the shortage of land for crop production exacerbates problems (MRC, 2010). Therefore, reduction in aquatic resources would likely have a severe impact on the rural population.

Given this cost replacement, estimates were established based on a 50 percent loss in fisheries production based on the production estimate from Table 18-3. Food replacements consist of aquaculture (farmed Pangasius catfish and tilapia) livestock (beef, pork and chicken) and rice.

Table 18-4. Food production (tonnes), water (km^3), land (km^2) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km^3 (percentage of agricultural water use)	Land required to replace fisheries in km^2 (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Pangasius catfish	93 912 (280.8)	0.16 (7.8)	41 (0.1)	0.3
Tilapia	72 769 (2079.1)	0.22 (10.6)	3 307 (4.2)	0.05
Beef	76 368 (135.4)	1.17 (57.3)	8 811 (58.7)	4.8
Pork	39 939 (36.1)	0.24 (11.6)	5 446 (36.3)	0.02
Chicken	125 782 (745.6)	0.54 (26.5)	3 375 (4.2)	0.3
Rice	106 915 (1.1)	0.24 (11.6)	234 (0.6)	0.01

Energy replacement (Table 18-4)

Replacement of capture fisheries with farmed Pangasius catfish would require 280 percent of the current Pangasius production in Cambodia (45 000 tonnes in 2015). Farmed tilapia would require the equivalent of 2 079 percent of current production (tilapia aquaculture in 2015 was 3 500 tonnes). Beef production would need to increase, equivalent to 135 percent of current beef production (beef production in 2014 was 69 205 tonnes). Chicken production would require the largest increase, equivalent to 745.6 percent of current production (chicken production in 2014 was 17 556 tonnes).

Water demand (Table 18-4)

Water resources would be impacted through the replacement of capture fisheries. Beef would require the largest increase of water use, equivalent to 57.3 percent of the agricultural water use in Cambodia (agricultural water use was 2.1 km^3 in 2006). Pork, rice and farmed Pangasius and tilapia as replacements would require similar amounts of water to replace fisheries, (0.16 km^3 to 0.24 km^3), equivalent to 7.8 percent to 11.6 percent of the agricultural water use from Cambodia.

Land requirements (Table 18-4)

Farmed Pangasius catfish replacement would require the equivalent of 0.1 percent of the area of the Tonlé Sap Lake during the wet season. Beef production would require 58.7 percent of the total pastureland area in Cambodia (pastureland area in 2014 was 15 000 km^2). Rice production would require the smallest increase in land conversion, equivalent to 0.6 percent of the total arable land area in Cambodia (arable land area in 2014 was 38 000 km^2).

Greenhouse gas emissions (Table 18-4)

Carbon emissions from a 50 percent loss in capture fisheries from Tonlé Sap Lake were estimated at 462 480 tonnes. The largest emission intensity would come from replacement of fisheries with beef (4.8 million tonnes), followed by Pangasius catfish (0.3 million tonnes), chicken (0.3 million tonnes), tilapia (55 317 tonnes) pork (22 090 tonnes) and rice 12 262 tonnes.

18.5 FISHERIES MANAGEMENT

The DoF and the Ministry of Agriculture, Forestry and Fisheries are the fishing authorities. The DoF is charged with the enforcement of the fisheries law. The objectives of DoF management are:

- Maintain the resource for food security for all rural people;
- To use additional production for income generation from export; and
- To assure that fisheries provide substantial input for the national economy (Lamberts, 2001).

Different laws and regulations apply to the different fisheries present within the lake basin. Larger commercial fisheries are subject to taxes and licence fees and are restricted to fishing only at certain times of year. Medium-scale fisheries are required to have a licence and are restricted to the number of gear that can be used. Small-scale or family-based fisheries are free to access aquatic resources, although some area restrictions are enforced (Van Zalinge *et al.,* 2001). Generally, traditional single-species management plans are difficult to apply given the complex multispecies and multigear nature of the fishery (Lamberts, 2001).

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19 AYEYARWADY (IRRAWADDY) RIVER

19.1 OVERVIEW

The Ayeyarwady River flows through the heart of Myanmar and covers 61 percent of Myanmar's total area. At 2 170 km long, the Ayeyarwady River is Myanmar's most important commercial inland river. The Ayeyarwady originates at the confluence of the Mali Hka and N'Mai Hka rivers in Kachin State (Myanmar), the headwaters of which originate in the southeastern Himalayas. The N'Mai rises in the Languela Glacier north of Putao (Myanmar). Downstream, a large delta area (290 km long and 240 km wide) consists of large fertile plains and supports an ecosystem of mangrove swamps and tidal estuaries. The delta supports a population of some 3 million people and provides around 60 percent of Myanmar's rice production (KDNG, 2007). The mean discharge of the Ayeyarwady River is around 13 500 m^3/s (Welcomme, 1985), and the river is the fifth most heavily silted river in the world (KDNG, 2007).

Table 19-1. Characteristics of the Ayeyarwady River

Country	Area of the river basin (km^2)	Percent area of the river in the country	Population of the river basin	Population density/km^2
Myanmar	362 264	90.32	28 044 395	77
People's Republic of China	21 440	5.35	1 981 233	92
India	17 375	4.33	2 891 984	172
Total	**401 079**	**100**	**32 917 612**	**144**

Fish diversity

There are varying estimates regarding the fish fauna composition of the Ayeyarwady River. KDNG (2007) estimated that there were 79 known fish species. But FishBase indicated 147 fish species. The river contains eight endemic species: *Hemibagrus peguensis, Mystus leucophasis, Cyprinus intha, Garra poecilura, Macrognathus zebrinus, Schistura acuticephalus, Schistura paucifasciata* and *Clupisoma roosae* (FishBase, 2017). The Ayeyarwady River is also the habitat for the Ayeyarwady Dolphin, which is classed as critically endangered by the IUCN (Smith, 2004).

19.2 FISHERIES OVERVIEW

The size and scale of fisheries activities vary from small-scale to large commercial operations. Fishing activities can be broken down into leasable fisheries, tender lot fisheries and open access fisheries. The leasable fisheries are almost exclusively key fishing areas on floodplains, which are primarily fished to capture migrating fish as they move off the floodplain. These lease holders hold exclusive rights to fish the lease area and can prevent access of other fishers in their area. There are an estimated 1 738 lease-controlled systems in the Ayeyarwady Division (lower floodplains and delta of the river). Tender lot fisheries are stretches of river for which fishing rights are allotted by the Department of Fisheries for the use of a specific type or number of gear (Baran *et al.,* 2017). Open access fisheries consist of all other areas and all other fishing operations. A unique form of fishing that takes place in the Ayeyarwady River is the cooperative fishery practised between Irrawaddy dolphins and cast-net fishers, in which the dolphins herd fish into a concentrated mass making it easier for fishers to catch fish (Smith *et al.,* 2009). Fishing is carried out on open waterbodies, streams, lakes, reservoirs and rice fields. Fish is second only to rice in the diet of Myanmar, but there is little information available on the patterns of consumption and the availability and types of fish consumed. However, there are similarities in the fisheries of the Ayeyarwady and the Mekong in Myanmar (FAO and NACA, 2003).

Fishing methods

The leasable fisheries on floodplains in the delta region are fished typically with barrage fences around the lease area where fish are collected in various traps or pens, but the lessee also has the sole right to use any gear to exploit fishery resources. Tender lot fisheries normally use a specified type of gear (usually stow nets). Larger-scale open fisheries often use bagnets set in the rivers, but generally the open nature of the fishery means that any fishing gear can be used. Some of the more popular gear includes moveable drop traps (locally known as *saung*), small stationary traps, cast nets, longlines and gillnets (FAO and NACA, 2003).

Fish trade

The value of Myanmar fisheries is not known but most fish caught in the Ayeyarwady Basin are for domestic consumption. Fish are usually sold in some preserved form (fermented, dried, as paste or salted) but small fish are also sold fresh. Demand for fish products is high, with fish exceeding other animal protein sources in local markets by a factor of 10:1 (FAO and NACA, 2003).

Employment

The number of fishers that participates in fishing activities in the Ayeyarwady River is not known, but based on the number of fishing licences, there were around 1.39 million fishers operating in inland water in Myanmar in 2000 and 2001, and there were 1 739 leased fishing areas in the Ayeyarwady Delta. However, this figure is based on licensee records and in practice, much of the small gear is not included (as licences tend to be neglected for smaller gear and concentrated on those fishing for profit). Also, fishers who only fish seasonally, occasionally and in rice-fields are not included in licensing (FAO and NACA, 2003).

Estimated fisheries production

Table 19-2 indicates the estimated fisheries production for the Ayeyarwady River (Department of Fisheries, 2017). But the figures are most likely an underestimation of actual production estimates. Within the Ayeyarwady River, all licensees must report their catches, but in reality it is only the larger leasable fisheries and larger fixed gear fisheries that report fish catches; to pay less tax, leasable fisheries often under-report catches. Also, rice paddy fisheries are not recorded under the Department of Fisheries but are recorded by the Department of Agriculture and Irrigation (FAO and NACA, 2003). The hidden production from unreported fishing and also the under-reporting of leasable fishing and licensed fisheries catch means the figures presented in Table 19-2 are not likely to be representative of actual production levels (FAO and NACA, 2003). Lastly, fisheries production from the Ayeyarwady region most likely includes marine catches, as this is the delta region, and the Department of Fisheries does not separate marine and freshwater catch.

Table 19-2. Estimated fisheries production for the Ayeyarwady River

Country/province		Catch estimate (tonnes)	Year	Reference
Myanmar	Kachin	19 432	2014	Department of Fisheries (2017)
	Ayeyarwady region (floodplain and delta)	1 179 485		
India	Manipur State	6 302	2014	Government of India (2014)
	Nagaland State	743		
People's Republic of China	Yunnan Province	1 926	2015	Zhao and Shen (2016)
	Total	**1 207 888**		

Fishery data from Myanmar were subject to a major reassessment in 2017. Prior to 2000, there was limited incentive to assess fish catches and low catch volumes during this time reflect substantial levels of under-reporting. But, post-2000, a 30-year plan for fisheries development saw a rapid growth in fishery production, which is thought to be a reflection of fishery targets rather than actual production increases (Baran *et al.,* 2017). Fish catches have consistently increased by 10 percent/year. But fishery statistics began to be questioned after 2009, especially after Cyclone Nargis in 2008, which caused the worst natural disaster in the history of Myanmar, when the average annual increase of reported fish catches remained constant at around 10 percent (FAO, 2017). Consequently, fish catches for the whole country were downgraded to 863 000 tonnes, leading to the assumption that the fishery data from the Ayeyarwady are overestimated.

Estimated fisheries production from the proportional area of the Ayeyarwady River Basin in states and provinces in India and the People's Republic of China is also outlined in Table 19-2 and represents a small proportion of the total production.

Status of the fisheries: catch trends

Capture fisheries for the Ayeyarwady River have been steadily increasing by an annual average of 13.8 percent each year. Fisheries production for Kachin State increased from 2 829 tonnes in 1985 (the first available year for fish data) to 19 432 tonnes in 2014. Similarly, for the Ayeyarwady region fisheries catches increased from 136 523 tonnes in 1985 to 1 179 485 tonnes in 2014 representing 78 percent of total inland fisheries production in Myanmar. This could be considered surprising given that Cyclone Nargis wiped out the fisheries sector in the Ayeyarwady Delta. Also, from a study conducted on the human–dolphin cooperative fishing by Smith *et al.* (2009), fishers from the study area on the Ayeyarwady River had noted a considerable decline in fish catches due to the rapid increase in illegal electric fishing. This is supported by Simmance (2013) who stated that fishers found that income from fishing had been declining for decades and that daily fish catches were barely enough for their survival.

Aquaculture

The Department of Agriculture and Irrigation has strict control over the conversion of rice lands to other uses as rice is the principal staple crop in the country. Consequently, this strict control is one of the strongest constraints to more widespread development of aquaculture in Myanmar. Despite this issue, small-scale aquaculture is present in the form of aquaculture ponds in the Ayeyarwady Delta. The favoured species are rohu (*Labeo rohita*) and common carp (*Cyprinus carpio*), but species of tilapia may also be found in larger ponds (FAO and NACA, 2003).

19.3 THREATS TO THE FISHERIES

Habitat modification

Myanmar has embarked on a shift from gas to hydropower and aims to make it the sole source of electricity by 2030 (Simmance, 2013). As part of this project, a seven-dam cascade has been proposed for the Ayeyarwady River and the Mali and M'Mai Rivers. The largest is the Myistone Dam on the confluence of the Mali and M'ai Rivers as they form the Ayeyarwady River, and it would inundate an area the size of Singapore. Located in one of the world's top biodiversity hotspots, the dam would displace 12 000 people and cause irreversible damage to Myanmar's key river system, as well as for downstream rice communities. In an environmental impact assessment (EIA) for the Myistone Dam experts found neglect of temporal and spatial scale of social and environmental impacts, and in a surprise move, the President of Myanmar cancelled the construction of the Myistone Dam in 2011. But the six other dams are still set for construction. If built, these dams would block migration routes, causing substantial losses to downstream fishery production and result in loss of prey for iconic species such as the Irrawaddy Dolphin (Simmance, 2013).

Land degradation is becoming an increasing problem in Myanmar, with soil erosion in upland agricultural areas being of particular concern, which has led to exceedingly high levels of greenhouse gas emissions. In the Irrawaddy Delta, the destruction of mangrove forests has been noted as a possible cause for the decline in fish catches and the area's increased vulnerability to natural disasters (Simmance, 2013).

Water quality

Mining operations within the Ayeyarwady River Basin are causing environmental degradation through habitat loss and degradation as well as declines in water quality. Myanmar is rich in minerals and gemstone deposits such as silver, gold, lead, sapphires and diamonds. Mining operations have shifted in intensity from small-scale operations to industrial operations over the last 20 years. Wastes from mining operations such as mercury, arsenic and cyanide are causing water pollution. Pollution levels in some areas are over the World Health Organization (WHO) guideline levels for pollutants in drinking water, particularly high levels of arsenic and cyanide in some areas of the basin. The degraded water quality could be a cause of the decline in fish stocks, but overfishing and exploitation cannot be overlooked (Bowles, 2013).

19.4 EQUIVALENT FOOD REPLACEMENT

Inland capture fisheries form an integral, but unrecognized contribution to food security in Myanmar. Freshwater fish contributed 25.77 kg/capita/year in 2013 and is second only to rice in the diet of Myanmar (FAO and NACA, 2003; FAO, 2017). Fisheries plays a large contribution to the nutritional security of the Myanmar people by supplementing the typical rice-based diet (FAO and NACA, 2003). Based on this, food substitution estimations were based on a 50 percent loss to the fishery production value in Table 19-2. Food substitutions constitute aquaculture (farmed common carp and Pangasius catfish), livestock (beef, pork and chicken) and rice. Replacement estimates were based on fisheries production in Myanmar only, given the small area and catch from the People's Republic of China and India.

Table 19-3. Food production (tonnes), water (km³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Common carp	362 239 (1964.3)	1.13 (3.8)	60 373 (15.0)	
Pangasius catfish	457 695 (1103.1)	0.78 (2.6)	195 (0.05)	1.58
Beef	372 191 (159.9)	5.73 (19.4)	42 945 (1403.4)	23.30
Pork	194 651 (23.3)	1.17 (3.9)	26 543 (867.4)	0.12
Chicken	613 021 (44.1)	2.65 (9.0)	16 449 (537.6)	1.45
Rice	521 068 (2.0)	1.17 (3.9)	1 142 (1.1)	0.06

Energy replacement (Table 19-3)

Aquaculture production would have to significantly increase to replace capture fisheries. Farmed common carp production increase is equivalent to 1 964 percent of current production levels (18 441 tonnes in 2015). Similarly, farmed Pangasius catfish production increase is equivalent to 1 103 percent of current production (41 493 tonnes in 2015). Beef production would have to increase by 150 percent to replace capture fisheries (2014 production was 232 804 tonnes). As the primary economic crop in Myanmar, replacement of rice production is small in terms of current production (replacement estimate of 521 068 tonnes), equivalent to 1.97 percent of current rice production in Myanmar.

Water demand (Table 19-3)

Replacement of capture fisheries with beef would have a significant impact on water usage, equivalent to 19.4 percent of agricultural water use in Myanmar in 2000 (agricultural water usage was 29.57 km^3). Pangasius catfish production would require the smallest water demand to replace capture fisheries, equivalent to 2.6 percent of agricultural water withdrawals in Myanmar. The remaining replacement items (pork, rice and farmed common carp) would require similar replacement values of 1.13 km^3 to 1.17 km^3, equivalent to 3.8 percent to 3.9 percent of agricultural water use.

Land requirements (Table 19-3)

Farmed Pangasius catfish production would require the smallest land conversion, equivalent to 0.05 percent of the Irrawaddy Basin area. Beef replacement production would require the largest land conversion, equivalent to 1 403 percent of the pastureland area in Myanmar (pastureland area was 3 060 km^2 in 2014). Pork production would require an expansion in land use, equivalent to 867 percent of the pastureland area in Myanmar.

Greenhouse gas emissions (Table 19-3)

Estimated carbon emissions from capture fisheries on the Ayeyarwady River were 2.25 million tonnes. Net increases in carbon emissions were highest for beef (23.30 million tonnes), followed by farmed Pangasius catfish production (1.58 million tonnes), chicken production (1.45 million tonnes), pork production (0.12 million tonnes) and rice (0.06 million tonnes).

19.5 FISHERIES MANAGEMENT

Myanmar's inland fisheries are managed on an 'open' or 'leasable' basis. The leasable fisheries are key fishing grounds that are leased by the Department of Fisheries on an auction basis every nine years to promote improved long-term management (FAO and NACA, 2003). The leaseholders have exclusive rights to the fishing area, including controlling access rights to it. The entire leasable fishery is closed from June to August during the spawning and recruitment season. The open fishery covers inland fisheries in all areas other than leasable fisheries. All fishing gear requires a licence, but licences tend to be ignored for smaller gear and instead licensing mainly applies to those fishing for profit. The open fishery occurs all year round and is technically considered illegal during the leasable closed season (FAO and NACA, 2003).

Governance of natural resources within the Ayeyarwady River Basin is also done through Myanmar's network of protected areas and parks, of which there are 33. In the basin, a protected area spans 70 km of the river and supports one-third of the river's population of the Irrawaddy Dolphin. However, these areas are considered too small and are increasingly at threat from competing pressures related to economic development and agricultural expansion (Simmance, 2013).

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20 SALWEEN RIVER

20.1 OVERVIEW

Also known as the Nu Jiang River in the People's Republic of China and Thanlwin in Myanmar, the Salween River (Table 20-1) flows for 5 400 km and is the second longest river in Southeast Asia after the Mekong, and is the only major river that flows freely with no dams in Southeast Asia (Aung, 2019). The river originates 4 000 m above sea level on the mountain Tangula in the Himalayas on the Tibetan Plateau, adjacent to the Mekong and Yangtze rivers in the 'Three Parallel Rivers' World Heritage Area. The river flows through Yunnan Province in the People's Republic of China, along the border with Thailand for 120 km and then into Myanmar before emptying into the Gulf of Martaban in the Andaman Sea. The main tributaries of the Salween are the Moei, Pang, Teng and Pawn Rivers. The Upper Salween is characterized by high elevation and deep gorges, in the middle reaches in Myanmar and Thailand, the river basin is mountainous with long narrow river valleys. The annual flow of the Salween from the People's Republic of China to Myanmar is 68.7 km^3; in Myanmar, the Salween drains about 20 percent of the territory and along the Thai border the flow is estimated at 200 km^3/year (FAO, 2016).

Table 20-1. Characteristics of the Salween River

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
People's Republic of China	137 051	52	3 872 502	28
Myanmar	109 495	41	4 835 736	44
Thailand	19 266	7	490 013	25
Total	**265 811**	**100**	**9 198 251**	**33**

Fish diversity

There are various estimates regarding the number of fish species in the Salween River, which are outlined in Table 20-2. Most come from the family Cyprinidae (96 species) (FishBase, 2017) and Salween Watch (2011) estimated that a third of the species are endemic. Most endemic species come from nine families (*Amblycipitidae, Ariidae, Cyprinidae, Mastacembelidae, Nemacheilidae, Psilorhynchidae, Schilbeidae, Siluridae* and *Sisoridae*) (FishBase, 2017).

Table 20-2. Fish diversity in the Salween River

Fish diversity	Endemic species	Introduced species
140–221	16–47	5

Sources: Revenga *et al.* (2000); Salween Watch (2011); FishBase (2017).

Fish introductions

The only documented fish introduction by FishBase is the mrigal carp (*Cirrhinus cirrhosis*) (FishBase, 2017). In addition, according to Chen *et al.* (2015) the exotic and invasive species *Abbottina rivularis, Oreochromis niloticus, Rhinogobius giurinus* and *Rhodeus ocellatus* were introduced into the Nu Jiang River (China).

20.2 FISHERIES OVERVIEW

Around 10 million people, representing at least 13 different ethnic groups depend on the Salween River Basin for their livelihoods. Fisheries are a major source of dietary protein, but fishing is rarely conducted as a full-time occupation and is instead carried out alongside other livelihood activities such as farming (FAO, 2016). Fishing is carried out on floodplains, mangroves and on the main channel itself (mainly in the lower reaches); the main fishing period is when fish are migrating off the floodplain at the end of the wet season (FAO, 2010; Aung, 2019). Fisheries of the Salween River are likely typical of a major river fishery in Southeast Asia, consisting of commercial, artisanal and subsistence fisheries (Welcomme *et al.,* 2016). Subsistence fishing is conducted for local consumption within the creeks and rivers using traditional methods; however, fish caught by many local fishers are not enough to meet consumption demands of villages and communities must rely on imported fish from other markets (Aung, 2019). Common species caught in artisanal and subsistence fisheries consist of snakehead murrel (*Channa striata*), walking catfish (*Clarias batrachus*), striped dwarf catfish (*Mystus vittatus*), yellowtail catfish (*Pangasius Pangasius*), paradise threadfin (*Polynemus paradiseus*), brushtooth lizard fish (*Saurida undosquamis*) and wallago (*Wallago attu*).

Fishing methods

Specific gear use in the Salween River fisheries is not known but is thought to be diverse with many local adaptations. Stow nets, locally known as tiger mouth nets, are important gear. They are large cone-shaped bag nets for use on large rivers. Other inland fishing gear includes staked and drift gillnets, trammel nets, hand lines, longlines, cast nets, fish traps and push nets, which are used widely on shallow water, lakes, small rivers and swamp areas. However, the use of large-scale push nets operated by mechanized boats is prohibited in Myanmar (FAO, 2010).

Fish trade

The direct value of fisheries products from the Salween River is not known, but in Myanmar about 80 percent of the fish landed are used for direct human consumption, mostly sold fresh or chilled. Large freshwater landing sites are not known, but fish are landed in thousands of small villages from where they are bought by village collectors who sell them onto larger-scale intermediaries (FAO, 2010).

Employment

Direct and indirect employment in Salween River fisheries is unknown, but according to FAO the estimated employment in inland capture fisheries in Myanmar is around 1.6 million (FAO, 2010). However, this figure is likely grossly underestimated, and an alternative FAO figure would suggest that more than 10 million from at least 13 ethnic groups depend on the Salween River Basin for their livelihoods, most of whom participate in fisheries activities throughout the year (FAO, 2016; International Rivers, 2017).

Estimated fisheries production

Table 20-3 indicates the estimated fisheries production for the Salween River by province for the People's Republic of China and Myanmar. The fishery catch from the People's Republic of China represents the catch from the proportional area that the basin occupies within the province (Zhao and Shen, 2016). This figure is likely overestimated for three reasons. Firstly, fisheries statistics from Myanmar consist of the production of fish and prawns, and as such, the production figure in Table 20-3 is overestimated as the fish production figures could not be separated from the prawn production figures. Secondly, fisheries production from Mon State in Myanmar most likely includes marine catch as this state is on the coast and statistics from Myanmar do not separate catch data into freshwater and marine catch.

Thirdly, fishery catches from Myanmar have been questioned by FAO since 2009 because the average annual increase of reported fish catches remained constant at around 10 percent despite the havoc caused by Cyclone Nargis in 2008 (FAO, 2017). In addition, independent stock assessments indicated that production was far lower than that reported in national statistics (Baran *et al.,* 2017). Fishery statistics for the last ten years have since been revised downwards, leading to the assumption that the Salween River fishery production is overestimated.

Table 20-3. Estimated fisheries production for the Salween River

State/province		Catch estimate (tonnes)	Year	Reference
People's Republic of China	Yunnan	3 408	2015	Zhao and Shen (2016)
Myanmar	Shan	7 013	2014	Department of Fisheries (2017)
	Kayah	858		
	Kayan	12 645		
	Mon	174 370		
Total		**198 294**		

Status of the fisheries: catch trends

According to official statistics of fisheries production in Myanmar, fisheries production has increased steadily since fisheries data collection began in 1985 (except for Kayah State which only reported catch data from 2000). Catches from the Salween River states in 1985 amounted to 19 861 tonnes, increasing to 194 886 tonnes in 2014. However, this is not the case for the whole basin; there are some areas where fish catches have declined. For instance, in the Darebauk River, one of the tributaries of the Salween, the fishery had been declining over the last ten years. Previously, there had been more than 1 000 fishing boats on the river but when the study was conducted in 2015 that figure had dropped to around 200 boats. In fishing villages along the Darebauk River, fishing had become unprofitable and many fishers had left fisheries due to high investment costs and low income. Villagers believe that the causes for declines in fisheries are overexploitation, high sedimentation and the effect of the tsunami in 2004 (Aung, 2019).

Aquaculture

Aquaculture practices on the Salween River are not known but fish farming does occur in Yunnan Province, People's Republic of China. Aquaculture production in 2013 was 156 096 tonnes (China Agriculture Yearbook, 2014), with tilapia and rainbow trout being some of the most farmed species in the province.

Recreational fisheries

Recreational fishing in Myanmar has yet to become established but increases in tourism mean that the unique lifestyles of fisher communities within the Salween River have tourist potential (FAO, 2010). In Thailand, carp fishing along the Salween and its tributaries in Mae Hong Son Province is becoming popular. Although the number of fishers and scale of catch is unknown, catch-and-release carp fishing is practised in most areas; fly fishing is the only method used by recreational anglers.

20.3 THREATS TO THE FISHERIES

Habitat modification

Although the Salween River is the last major free flowing river in Southeast Asia, 13 dams in the Chinese portion of the Salween River and a further six dams in Thailand and Myanmar are under consultation. The cascade of dams in the Chinese portion of the basin would be the largest cascade of hydroelectric dams in the world. It is also estimated that 50 000 people would require resettlement to make way for the 13-dam scheme (Mekong Eye, 2017). If built, the impact of the 13-dam cascade would be significant. The Three Parallel Rivers area in Yunnan Province is believed to support over 25 percent of the world's, and nearly 50 percent of China's animal species according to the United Nations Educational, Scientific and Cultural Organization (UNESCO). The dams would disrupt the freshwater ecology and threaten one-third of fish species in the river (International Rivers, 2017). The fauna and livelihoods of people within the region appeared to be secure, when in 2004 Chinese Premier Wen Jiabao announced the suspension of all projects on the Salween River pending more environmental studies (Mekong Eye, 2017). However, as part of China's 12th Five Year Plan officials revealed plans to resume consultation and planning of the dams (International Rivers, 2017).

In Myanmar, five dams along the Salween River are planned, and at 238 m height, the Tasang Dam would be the largest in Southeast Asia with a reservoir extending almost to the Chinese border. Construction of the Tasang Dam has been accused of causing human rights abuses and widespread environmental damage (SEARON, 2004; Magee and Kelly, 2009; International Rivers, 2017; Mekong Eye, 2017). A Shan advocacy group stated that over the last ten years, the Myanmar army has relocated more than 60 000 villagers from areas adjoining the dam site. In addition, among the other environmental costs, the Tasang Dam will flood pristine teak forests and other proposed dams will inundate parts of the Salween National Park and Salween Wildlife Sanctuary (International Rivers, 2017). Opposition persists against the development of dams in Myanmar, but public participation in decision-making processes is non-existent and measures to protect the environment are ignored. If constructed, the cascade of dams in Myanmar would have a severe impact on the livelihoods of communities within the basin and surrounding area (SEARON, 2004).

20.4 EQUIVALENT FOOD REPLACEMENT

Given that fisheries form an integral part of people's livelihoods and that fish form a major component of animal protein, the loss of capture fisheries would therefore be detrimental to fishing communities. Additionally, the huge potential environmental and social impact of the proposed hydroelectric dam construction within the basin and threat to one-third of fish species in the Chinese portion of the river are significant. Equivalent food replacement estimates were based on a 50 percent loss to capture fisheries production (Table 20-3). Replacement food sources consist of aquaculture (common carp, Pangasius catfish and tilapia), livestock, (beef, pork and chicken) and crops (rice).

Table 20-4. Food production (tonnes), water (km³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Pangasius catfish	101 851 (254.5)	0.13 (2.5)	32 (0.01)	0.25
Common carp	59 912 (1.8)	0.19 (3.7)	9 985 (3.8)	
Tilapia	58 657 (2.9)	0.18 (3.4)	2 666 (1.0)	0.02
Beef	61 558 (0.9)	0.95 (18.6)	7 102 (1.8)	3.85
Pork	32 194 (0.1)	0.19 (3.8)	4 390 (1.1)	0.02
Chicken	101 390 (0.6)	0.43 (8.6)	2 720 (0.7)	0.24
Rice	86 181 (0.03)	0.19 (3.8)	188 (0.01)	0.01

Energy replacement (Table 20-4)

Pangasius aquaculture production would need to increase with production equivalent to 245 percent of current production from the basin countries (Myanmar was the only country that produced farmed Pangasius catfish in 2015 at 41 493 tonnes). Chicken production would require the largest increase in production to replace capture fisheries, equivalent to 0.6 percent of production levels in 2014 (chicken production 2014 was 15.9 million tonnes). Replacement estimates for farmed tilapia and common carp would be equivalent to 2.9 percent and 1.8 percent of production levels in 2015 (1.9 million tonnes and 3.4 million tonnes for farmed tilapia and carp, respectively).

Water demand (Table 20-4)

Water withdrawals in the Salween River Basin are estimated at 5.1 km³ of which Myanmar accounts for 63 percent, China 32 percent and Thailand 5 percent. Irrigation accounts for 4.2 km³ of water usage.

Replacement of capture fisheries with beef would have the largest impact on freshwater resources with the equivalent of 18.6 percent of the estimated water withdrawal from the river required. Farmed Pangasius catfish production would require the smallest water demand, equivalent to 2.5 percent of the estimated water extraction from the river. The remaining replacement foods require similar amounts of water to replace fisheries, equivalent to 3.4 percent to 3.7 percent of estimated agricultural water extraction from the river.

Land requirements (Table 20-4)

Replacement of inland capture fisheries with common carp aquaculture would require the largest expansion in land use. Farmed common carp production would require 3.8 percent of the Salween River basin area. Beef production would require the largest land conversion from a terrestrial replacement food, equivalent to 1.8 percent of the pastureland from the Salween River Basin countries (pastureland area was 403 894 km^2 in 2014). Rice production would require the smallest land conversion, equivalent to 0.01 percent of arable land in use in 2014 in the basin countries (arable land area was 1.4 million km^2 in 2018).

Greenhouse gas emissions (Table 20-4)

Estimated carbon emissions from 50 percent of the capture fisheries for the Salween River were 366 386 tonnes. Net increase in emissions from alternative food sources would be highest for beef (3.85 million tonnes), followed by chicken (0.24 million tonnes), farmed Pangasius catfish (0.25 million tonnes), pork (0.02 million tonnes), farmed tilapia (0.02 million tonnes) and rice (9 714 tonnes).

20.5 FISHERIES MANAGEMENT

The People's Republic of China, Myanmar and Thailand currently do not have an agreement yet on the use of the Salween River, allowing each country to have free use of the river. In 1989, a joint technical committee was established between Thailand and Myanmar, which consisted primarily of representatives of the power companies of the two countries. Since then, the committee has continued to meet to pursue feasibility studies to collaborate on the construction of five dams on the Salween River in Myanmar. However, no project or management body has been implemented nor any basin-wide plan created. Also, the People's Republic of China has not been included in discussions, nor has it included Thailand or Myanmar in its plans for development of the Salween River. Additionally, while there have been meetings at the state level, local populations have not been included in the decision-making process. While efforts are being made in terms of river planning to avoid interstate conflict at the state level, large-scale water projects may create or exacerbate intrastate conflicts at the local level. Given that the Salween River is in the early stages of development, it is encouraging that technical and management discussions have been proceeding and that cooperation exists between the basin nations. This could allow for integrated management of the Salween River from the onset of development (Wolf and Newton, 2008).

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21 MAHAKAM RIVER

21.1 OVERVIEW

The Mahakam River (Table 21-1) is the largest river that drains East Kalimantan Province, Indonesia and is the second longest river, covering a length of 920 km of which 500 km are navigable for commercial vessels (Christensen, Mulu and Akbar, 1986). The river has a total discharge of between 600 m^3/s and 6 000 m^3/s (Christensen, Mulu and Akbar, 1986). The river can be divided into five regions: the western mountains, an upland area fringing them, a central floodplain, a narrow strip of hills parallel to the coast and the delta. The floodplain in the central region is known as the Middle Mahakam Area (MMA) and covers 5 000 km^2. The floodplain is characterized by swamp forests and extensive grasslands, and is home to the juveniles of many commercially important species. The freshwater habitat of the MMA can be subdivided into five major groups: large and small rivers, lakes, small waterbodies and swamps (Christensen, 1992; Christensen, 1993a).

Table 21-1. Characteristics of the Mahakam River

Area of the river basin (km^2)	Percent area of the river in the province	Population of the river basin (1984)	Population density/km^2
77 700	100	99 187	2

Fish diversity

Christensen (1992) identified 145 indigenous species from 35 families in the Mahakam River. Cyprinidae is the most abundant family, comprising approximately 32 percent of the fish species, seven Siluriformes families make up a further 26 percent. The Mahakam River is also habitat for a subpopulation of Irrawaddy dolphin (*Orcaella brevirostris*) which is classed as critically endangered by the IUCN on account of population declines caused by gillnet entanglement and deliberate kills (Jefferson *et al.,* 2008).

Fish introductions

According to Christensen (1992) there are nine introduced species: common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*), African catfish (*Clarius gariepinus*), guppy (*Poecilia reticulate*), Nile tilapia (*Oreochromis niloticus*), Mozambique tilapia (*O. mossambicus*), kissing gourami (*Helostoma temminckii*), snakeskin gourami (*Trichopodus pectoralis*) and the giant gourami (*Osphronemus goramy*).

21.2 FISHERIES OVERVIEW

The floodplain fishery on the Mahakam River is one of the most important freshwater fisheries in Indonesia. The fishery is purely artisanal, but traditional fishing gear made from natural materials is being replaced by modern nets (Christensen *et al.,* 1987). A large portion of the catch is landed between February and July when decreasing water levels force fish to leave the floodplains making them easier to catch (Christensen, 1992). Fifteen fish and one crustacean (freshwater prawn) composed 90 percent of the marketed catch by both weight and value, and a further 11 species were frequently caught and eaten by fishers' families. Four species comprised almost two-thirds of the marketed fish catch: the kissing gourami, banded snakehead (*Channa striata*), snakeskin gourami and a small cyprinid (*Thynnichthys vaillanti*) (Christensen 1993a).

Fishing methods

There are around 23 different types of fishing gear used in the MMA which can be classified into three categories: fishing lines (handlines, setlines, set longlines and hookless longlines), traps (basket traps, bamboo funnel traps, floating funnel traps, spring traps and slit traps) and nets (cast nets, gillnets, lift nets, scoop nets and beach seines) (Christensen, 1992). Illegal fishing methods are beach seine nets, use of electricity and plant poisons (Christensen, 1993c). Formerly, cast nets and gillnets were very popular fishing gear and were owned by nearly all fishing households; few households possessed handlines, which were mainly utilized by women and children. After the 1980s, artificial gillnets became widely available and increased in popularity and replaced expensive hand-made gillnets (Christensen, 1993a).

Fish trade

In terms of value, the freshwater prawn, Pangasius catfish and featherback contribute the most value to fish catches. The average price per fish was IDR 1 260 (USD 19.56) for Pangasius, IDR 1 660 (USD 25.77) for *Notopterus chitala* and IDR 1 870 (USD 29.04) for *Macrobrachium rosenbergii* when sold fresh (Christensen, 1993a). Christensen (1993b) estimated that the cash income from the Mahakam floodplain fishery was IDR 12.28 billion in 1984 (approximately USD 190 million), but this value does not include secondary activities.

Employment

Of the 18 000 households living in the area, some 5 800 people are full-time fishers earning approximately 60 percent to 95 percent of their annual income through fishing. A further 6 200 households catch fish on a part-time basis, generating 35 percent to 85 percent of their total annual income and an unknown number of people are involved in support services such as boatbuilding, net making and fish marketing (Lorot, 1990).

Estimated fisheries production

Table 21-2 indicates the estimated fisheries production from the Mahakam River. Dutch colonial authorities collected the earliest data on the fishery; this was in the form of scattered departmental reports, which were of little use. In the 1970s the German Government set up a development programme in the MMA, based on short-term studies that were conducted on various aspects of the fishery. However, the only comprehensive studies conducted on the fishery, catch composition and catch estimates have been by Christensen (1988; 1993a, 1993b, 1993c). The estimated annual fishery production of the MMA floodplain is between 15 000 tonnes and 35 000 tonnes (Christensen, 1988; Christensen, 1993a). Since the 1970s landings have ranged around 20 000 tonnes, apart from 1982, 1984 and 1985 when exceptional catches of 26 000 tonnes to 35 000 tonnes were recorded. Since then, the fishery has been declining from a high of 31 000 tonnes in 1984 to a low of 12 350 tonnes in 1989 (Christensen, 1993c). The level of flooding seems to have a positive effect on fishery production, with high levels of flood (more than 10 m) corresponding with high levels of fish catch in 1982 and 1984. Given the age of the data, the production figure in Table 21-2 is likely an overestimation of current production in the basin.

Table 21-2. Estimated fisheries production for the Mahakam River

Catch estimate (tonnes)	Year	Reference
15 525	1990	Christensen (1993c)

Status of the fisheries: catch trends

Fish catch levels from the Mahakam River have been steadily declining since the mid-1980s and there has been much variation in catch levels for individual fishers. The average yearly catch for full-time fishers rose from 2 917 kg in 1981 to 5 731 kg in 1985, falling to 1 840 kg in 1987. Catches for part-time fishers have also varied from 1 490 kg in 1985 to 1 603 kg in 1986, but catches have since declined to 971 kg in 1987. Generally, between 20 kg and 125 kg of fish are landed daily by each fisher (Christensen, 1993b). Fishing effort was high in the 1980's, with full-time fishers working around 287 days/year (Christensen, 1993b), however there are no more recent data other than those presented here, which may not be representative of the current fishing effort.

Aquaculture

Fish farming has been conducted in the Mahakam River Basin since the early 1980s, where some 1 200 tonnes of fish were produced in 3 000 cages in 1984 (Christensen, 1988), valued at USD 480 000.

However, aquaculture practices were almost decimated in 1984 due to an epidemic, which saw the number of cages reduced to almost zero. Nevertheless, by 1992, at least 2 000 cages were back in operation (Christensen, 1993b). Introduced species, common carp, Mozambique tilapia, Nile tilapia and African catfish have also been cultured in fish cages (Christensen, 1993a).

Recreational fishing

Recreational fishing is not common in Indonesia and the Mahakam River, but a small number of hobbyists have started sport fishing around large Indonesian cities (FAO, 2011).

21.3 THREATS TO THE FISHERIES

Overexploitation and overfishing

The Mahakam River supports a productive fishery, but the fishery is considered likely to be overexploited (Christensen, Mulu and Akbar, 1986) due to growing population fishing pressure. However, profit margins from fishing are high, or higher than those from other agricultural activities, where the earnings are lower than other activities. This makes fishing an attractive source of income compared to other livelihood options (Christensen, 1993b).

There are several indictors of overfishing in the Mahakam River, for instance a decrease in the average size at first maturity as well as a decrease in CPUE and in the total catches of certain species (Christensen *et al.,* 1987). For instance, the cyprinid *Chela oxygastroides,* which is caught with a fine-meshed beach seine and lift nets. Fully-ripe, undersized females with juvenile colouration were collected from the heavily fished lake in 1987 (Christensen, 1993b). Changes to breeding condition before full maturity is a last-ditch mechanism to survive heavy fishing pressure and is considered a strong indicator of overexploitation (Welcomme, 1979). Similar observations have been made for at least 15 other fish species, which is an indicator that fishing intensity has increased. Catches of the freshwater prawn *Macrobrachium rosenbergii* have increased disproportionately, as predation pressure on the prawn may have decreased as larger predators were removed. Most, if not all of the recorded changes were attributed to the use of efficient fishing gear (Christensen, 1993b).

Habitat modification

Since the 1980s the Mahakam Wetland has been increasingly threatened by a variety of anthropogenic factors such as deforestation, forest fires, mining and pollution (WWF, 2005). In 2003, it was estimated that 66 percent of the East Kalimantan rain forest had disappeared over the past 25 years (de Jong *et al.,* 2015). Also, extensive land and forest fires during 1997 and 1998 have affected 75 percent to 82 percent of the swamp forest. These fires can have a detrimental impact on water quality, causing increases in turbidity and pH (Earl and Blinn, 2003). Furthermore, other research has found that local communities use fire for agriculture and fishing (to clear sailing routes or trap fish in a concentrated area) (Chokkalingam, Kurniawan and Ruchiat, 2005), however, the exact impact of these deliberate fires on the fisheries of the MMA is not known.

21.4 EQUIVALENT FOOD REPLACEMENT

Fishing in the Mahakam River is of huge economic importance, with fishing contributing 75 percent to 95 percent of full-time fishers' annual income and 30 percent to 85 percent for part-time fishers (Christensen, 1993b). As such, the loss of fishing activities would be detrimental to those who depend on the fishery for their livelihoods and income. Replacement estimates were established for a 50 percent reduction in capture fisheries production (Table 21-2). Replacement food consists of aquaculture (common carp and tilapia), livestock (beef, pork and chicken) and rice.

Table 21-3. Food production (tonnes), water (million m³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (thousand tonnes)
Tilapia	4 592 (0.4)	14.6 (0.02)	209 (0.3)	1.19
Common carp	4 690 (1.0)	13.7 (0.02)	781 (1.0)	
Beef	4 819 (1.0)	74.3 (0.08)	556 (0.5)	301.74
Pork	2 520 (0.1)	15.1 (0.02)	343 (0.3)	1.39
Chicken	7 938 (1.1)	34.3 (0.04)	213 (0.2)	18.80
Rice	6 474 (0.01)	15.0 (0.02)	15 (0.006)	0.77

Energy replacement (Table 21-3)

Aquaculture and beef would require similar replacement production. These values are equivalent to 1.0 percent, 0.4 percent and 1.0 percent of current production (production was 461 107 tonnes, 1.0 million tonnes and 497 669 tonnes for common carp, tilapia and beef in 2014 and 2015). Chicken production would require the largest amount to replace kilojoules from capture fisheries, equivalent to 1.1 percent of current production (2014 production was 758 999 tonnes).

Water demand (Table 21-3)

Beef production would require the largest replacement water use, equivalent to 0.08 percent of agricultural water use in Indonesia (agricultural water use in 2000 was 92.7 km³). Chicken production would require roughly half the replacement water, equivalent to 0.04 percent of agricultural water use in Indonesia. The remaining replacement items require a similar water demand for farmed common carp, farmed tilapia, pork and rice production, equivalent to 0.02 percent of agricultural water use.

Land requirements (Table 21-75)

Land conversion required for beef production would be highest, due to the lower livestock stocking densities in Indonesia. Land expansion for beef production would be equivalent to 0.5 percent of pastureland in Indonesia (2014 pastureland area was 110 000 km²). Farmed common carp would require the equivalent of 1.0 percent of the Mahakam River Basin area.

Greenhouse gas emissions (Table 21-3)

Estimated carbon emissions from a 50 percent loss to capture fisheries in the Mahakam River were 29 183 tonnes. Replacement of capture fisheries would result in a net increase in emissions, the largest of which would come from beef (0.3 million tonnes), followed by chicken production (18 802 tonnes) pork production (1 394 tonnes) farmed tilapia (1 194 tonnes) and rice cropping (773 tonnes).

21.5 FISHERIES MANAGEMENT

National management strategies

The legislation that governs fishery management is covered in the Fishery Law (Law No. 45/2009) and the Autonomy Law (Law No. 32/2004). The Autonomy Law established that the fishery sector in the provinces is under the responsibility of the provincial government. This is further subdivided to the regency government (local mayor), who has some responsibilities for fisheries that are reported to the provincial government (FAO, 2011). The Fisheries Law sets out regulations for fishing gear, allowable catch and allowable gear, however, there are no specific laws for inland fisheries.

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22 PEARL RIVER (ZHUJIANG)

22.1 OVERVIEW

The Pearl River (Table 22-1) is the largest river in Southern China and third longest river in the People's Republic of China , after the Yangtze and Yellow rivers and flows for a length of 2 218 km with a mean annual discharge of 3.3 $x10^{11}$ m^3 (the second largest in China) (Tan *et al.,* 2010). The river flows through parts of six Chinese provinces and originates from the Maxiong Mountain in Yunnan Province in the Xijiang drainage basin (PRWRC, 1991). The Pearl River is made up of three major tributaries: The Xijiang (West River), Beijiang (North River) and the Dongjiang (East River), which converge at the Pearl River Delta (42 800 km^2 floodplain) and then discharge into the South China Sea. The Xijiang is the largest and longest tributary of the Pearl River, flowing for a length of 2 075 km over a catchment of 353 120 km^2 representing 77.83 percent of the total Pearl River Catchment (Leung Sze-Iun, 2007).

Table 22-1. Characteristics of the Pearl River

Country	Area of the river basin (km^2)	Percent area of the river in countries
People's Republic of China	442 100	**97**
Viet Nam	11 590	**3**
Total	**453 690**	**100**

Fish diversity

The fish diversity of the Pearl River and its tributaries is outlined in Table 22-2. The Xijiang River contains 12 endemic species, six of which are from the genus *Anabarilius* spp. (FishBase, 2017). The Pearl River contains 17 endemic species, 14 of which are cyprinids, the remaining three are Nemanchilidae, Percichthyidae and Siluridae (FishBase, 2017). The estimates from FishBase differ from those in the literature. Liao *et al.* (1989) stated that the Pearl River once supported 381 fish species, with high endemism of around 120 species. The Pearl River is also habitat for the rare Chinese sturgeon, which is classed as critically endangered by the IUCN (Qiwei, 2010). By 2005, it was estimated that 92 species of fish in the Pearl River were endangered (PRWRC, 2006b).

Table 22-2. Fish diversity of the Pearl River and its major tributaries

River	Fish diversity	Endemic	Introduced
Pearl	136	17	
Beijiang	25		
Xijiang	174	12	2
Source: FishBase (2017).			

22.2 FISHERIES OVERVIEW

Little is known about the fishing activities on the Pearl River; studies confined to inland freshwater species or communities are relatively scarce and data gaps exist (Leung Sze-lun, 2007). The People's Republic of China has a long history of fishing and fish culture and has abundant fisheries resources. Harvesting of natural fish stocks and other aquatic organisms in rivers, lakes and reservoirs used to be a major industry in inland waters and a valuable source of edible fish for communities in inland areas. The most important species for capture fisheries are common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*) bighead carp (*Aristichthys nobilis*), grass carp (*Ctenopharyngodon idella*), black carp (*Mylopharyngodon piceus*), crucian carp (*Carassius auratus*), the catfishes *Coreius heterodon, Coreius guichenoti* and *Coilia ectene*, mud carp (*Cirrhinus molitorella*), Chinese shad (*Macrura reevesii*) and silver fish (*Reganisalanx brachyrostralis*). Increased freshwater catches can be attributed to freshwater stocking of natural waterbodies, which is an effective measure to increase catches form natural waterbodies. Major species for stocking are silver carp, bighead carp and common carp (Zhong and Power, 1997).

Fishing methods

Common fishing gear in the People's Republic of China includes set nets, gill- and drift nets, purse seines, hook and line, and longlines (FAO, 2001). Illegal fishing methods, such as electrofishing, use of poisons and explosives are less frequent due to new legislation on explosive and pollution control. But electrofishing, which is totally forbidden, remains popular throughout the country (Zhao, Gozian and Zhang, 2016).

Employment

Table 22-3 indicates the 2013 participation in fisheries from provinces that the Pearl River flows through according to the proportional area of the province that the river flows through. The total number of fishers participating in fishing activities on the Pearl River was 498 116, with a higher portion of people participating in fishing on a part-time basis (China Agriculture Yearbook, 2014). The number of fishers has gradually increased because many rural workers along the rivers have joined the fishery, lured by the potential for high profits from selling fish (Zhong and Power, 1997). Additionally, Liao, Lu and Xiao (1989) reported that the number of fishing boats on the Guangdong section of the Pearl River Delta had increased from 7 156 in 1975 to 9 483 in 1982. However, as fishery participation estimated by province it may be possible that not all fishers in each province fish in the Pearl River, therefore the figures in Table 22-3 could be an overestimation.

Table 22-3. Employment in Pearl River Basin fishing activities in 2013

Province	Full-time fishers	Part-time fishers	Fish farmers
Yunnan	2 011	18 089	12 509
Guizhou	2 468	39 663	29 132
Guangxi	58 391	256 350	257 902
Hunan	1 101	8 545	7 191
Guangdong	97 005	138 806	191 618
Total	**160 976**	**461 454**	**498 116**

Source: China Agriculture Yearbook (2014).

Estimated fisheries production

Table 22-4 indicates estimated fisheries production from the proportional area of each province that the main stem of the Pearl River (and its tributaries) flows through (Zhao and Shen, 2016). Freshwater studies on the Pearl River are confined to inland freshwater species or communities in the region and data are relatively scarce with gaps. Consequently, there is not much information regarding the state of fishery resources in the river. The fishery catch from Guangdong Province could primarily comprise marine catches as it is a coastal province and therefore the figures in Table 22-4 could be an overestimation of fish catches.

Table 22-4. Estimated fisheries production for the Pearl River

Province	Catch estimate (tonnes)	Year	Reference
Yunnan	5 587	2015	Zhao and Shen (2016)
Guizhou	4 619		
Guangxi	109 853		
Hunan	2 518		
Guangdong	47 259		
Total	**169 836**		

Status of the fisheries: catch trends

There are no official data on catches from the Pearl River and it is difficult to assess the catch trends. Fishers generally agree that catches have been declining over the past two decades, with once common species such as carp and catfish now being rare. The fishery of the Pearl River peaked in the 1950s but had declined by the 1980s. Catches of the Chinese shad (*Tenualosa reevesii*) declined 80 percent between the 1950s and 1980s and it has virtually disappeared from the river, which once supported a profitable fishery (Wang, 2003). There have been no reported catches of Chinese sturgeon in recent years – the fishery once yielded around 400 000 kg in the 1930s from the Xijiang River alone (China Daily, 2011).

Aquaculture

Aquaculture production from the provinces that make up the Pearl River was 1.60 million tonnes in 2013 (China Agriculture Yearbook, 2014). More than 40 species have been cultured, most of which are carp. Those contributing most to the yield include silver carp, bighead carp, grass carp, black carp, common carp, mud carp, crucian carp and Nile tilapia (Zhong and Power, 1997).

Prior to 1960, the fry of four major cultured fish (silver carp, bighead carp, grass carp and black carp) were obtained from the middle and lower reaches of the Pearl River. Successful artificial propagation of the four species in the 1960s greatly stimulated fish culture. Stocking has increased the fish catches along the Pearl River, for instance between 1980 and 1984, 166 fingerlings were released into distributaries of the Pearl River. As a result, the catch per unit area increased from 88.5 kg/ha in 1981 to 157.5 kg/ha in 1984 (Feng 1987). Stocking has been used as a method to improve wild fish catches in the Pearl River; in 2006 more than 500 million carp fry were released into the Dongjiang River, along with 150 million freshwater fish and the critically endangered Chinese sturgeon to increase the fishery resources of the river (South, 2006).

22.3 THREATS TO THE FISHERIES

Water quality

The Pearl River Delta is one of the most developed regions in the People's Republic of China. Rapid industrialization and polluting industries as well as urbanization have put considerable pressure on the river. The overall quality has been improving with Grades I–III (water standards acceptable for drinking) increasing from 91 percent to 94 percent of the monitored river length. However, this is not reflected basin-wide; in the Pearl River Delta, 24 percent of the assessed river length was classified as Grade V+ in 2015 and 39 percent of the river water was considered unfit for human contact (Grades IV, V and V+) (Hu, 2017). Studies by Leung *et al.* (2014) found significant concentrations of lead and nickel in tilapia and mandarin fish muscle. These concentrations were above the legal permissible limits for human consumption. Arsenic levels were also high in blackbass, snakehead, grouper and snapper, in addition to tilapia and mandarin fish, which were also above the legal permissible limit. Toxic metal contamination of fish threatens human health through consumption of contaminated fish (Leung *et al.,* 2014). In the past, seriously polluted waters caused fish kills in the Pearl River; in the early 1980s high levels of contaminants had eliminated fish from 5 percent of the total river length (Wang, 1990).

Overexploitation and overfishing

Freshwater resources of the Pearl River have been exploited at an increasing rate, with some species now considered to be overexploited or fully exploited (Li, 2005). Destructive fishing methods, such as the use electrofishing and explosives, have devastated already depleted fish stocks (Liao, Lu and Xiao, 1989). A combination of rapidly rising population and need for food and ineffective freshwater management have meant fishery resources have become overexploited.

Fish stock structures have undergone changes over the past decades. Older mature fish have disappeared and younger fish now dominate the fish catches; moreover the time at which fish become sexually mature has also decreased (Leung Sze-Iun, 2007). However, as the status of fish stocks within the river is unknown it is difficult to assess the long-term impact of high fishing pressure. Fishing bans have been implemented along the length of the Pearl River and its tributaries, the most recent in 2011 in which fishing on some 5 365 km of the river was forbidden for four months in an effort to allow fish stocks to recover (Jin, 2011).

Habitat modification

An estimated 14 000 reservoirs and 13 657 hydropower stations have been built along the Pearl River (PRWRC, 2004). Dams would appear to have impacted fish in the Pearl River, particularly the anadromous Chinese shad (*T. reevesii*), a highly valuable species; *Clupanodon thrissa* and mud carp (*Cirrhinus molitorella*) have been eradicated (Liao, Lu and Xiao, 1989). Sluice gates for flood control and hydropower facilities have prevented some major commercial fish from migrating freely to rivers to spawn.

22.4 EQUIVALENT FOOD REPLACEMENT

Given the relatively unknown status of the fish stocks in the Pearl River and the threat faced by anthropogenic stressors such as water pollution and overfishing, replacement estimates were based on a 50 percent loss to fishery production (Table 22-4). Replacement food items consist of aquaculture (common carp and tilapia), livestock, (beef, pork and chicken) and rice cropping.

Table 22-5. Food production (tonnes), water (km³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Common carp	51 314 (1.6)	0.2 (0.04)	8 552 (1.9)	
Tilapia	50 239 (3.0)	0.2 (0.04)	2 238 (0.5)	0.01
Beef	52 273 (0.8)	0.8 (0.3)	6 083 (0.2)	3.30
Pork	27 573 (0.05)	0.2 (0.04)	3 760 (0.1)	0.02
Chicken	86 839 (0.7)	0.4 (0.1)	2 330 (0.06)	0.21
Rice	73 813 (0.04)	0.2 (0.04)	162 (0.02)	0.008

Energy requirements (Table 22-5)

China is the largest aquaculture producer in the world and in terms of current production the replacement values are equivalent to 1.6 percent and 3.0 percent for common carp and tilapia respectively (2015 production was 3.17 million tonnes and 1.70 million tonnes for common carp and tilapia, respectively). Chicken production would require the largest increase in production, equivalent to 0.7 percent of current production (2014 production was 12.83 million tonnes). Pork production would require the smallest replacement value, equivalent to 0.05 percent of current pork production (2014 pork production was 55.39 million tonnes).

Water demand (Table 22-5)

Replacement beef production would require the largest amount of water to replace capture fisheries, equivalent to 0.3 percent of agricultural water withdrawals in China (2013 agricultural water use was 392.2 km³). Aquaculture products would require the lowest water demands of 0.2 km³, equivalent to 0.04 percent of agricultural water use.

Land requirements (Table 22-5)

Farmed common carp production would require the largest land conversion, equivalent to 1.9 percent of the Pearl River Basin area (Table 22-76). This figure could be reduced through an improvement in farming technologies. Beef production would require the equivalent of 0.2 percent of pastureland (2014 pastureland area was 3.92 million km^2).

Greenhouse gas emissions (Table 22-5)

Estimated carbon emissions from 50 percent loss of capture fisheries in the Pearl River were 242 776 tonnes. Replacement of capture fisheries with alternative food sources would result in a net increase in carbon emissions. Replacement emissions would be highest for beef (3.30 million tonnes), followed by chicken production (0.21 million tonnes), pork production (15 251 tonnes) farmed tilapia (13 071 tonnes) and rice (8 465 tonnes).

22.5 FISHERIES MANAGEMENT

National management strategies

In the People's Republic of China, the provincial governments are responsible for water management issues at the local level, but for some large rivers there are management authorities for particular river basins to oversee water management issues for the entire basin across different provinces, such as the Pearl River Water Resources Committee. The Chinese Government has issued various legislations and policies related to the protection of freshwater biodiversity, such as the China National Wetlands Conservation Action Plan (China Daily, 2000). Following the formation of a wetland management plan in Guangdong in 2006, 43 wetland conservation areas will be established by 2030 (Guangdong Forestry News, 2006). Also, various reserves have been proposed to protect endemic freshwater species.

Specific river basin management outlines the environmental protection of the Pearl River Delta, through the Environmental Protection Programme of the Pearl River Delta (2004–2020). This programme divides the Pearl River Delta into three ecological functional zones, which are further subdivided into 80 subzones according to the sensitivity of the ecological environment. In total, around 5 058 km or 12 percent of the Pearl River Delta is considered as a protection zone, comprising ecologically sensitive areas, such as nature reserves which local governments are obliged to protect. The programme has specific focus on pollution controls for water and air, and focuses on four areas: sewage treatment, ecological safety screening, desulphurization of coal-powered plants and early warning systems for environmental monitoring. In addition, a specific set of targets has been set for each of the nine delta cities for ecological protection, water environment protection and solid waste management.

Currently there is no integrated river basin management programme for the Pearl River. This would be a fundamental framework for the coordinated management and development of the water, land and biological resources within the river basin to maximize economic and social benefits from the conservation and rehabilitation of freshwater ecosystems (CCICED Task Force, 2004). Under an initiative between the provinces of Guangxi, Yunnan and Guizhou in the headwaters, and Guangdong in the delta, afforestation programmes in the headwaters of the Xijiang were carried out to mitigate the impacts of saline intrusion near coastal regions (PRWRC, 2006a).

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23 YANGTZE RIVER (CHIANG JIANG)

23.1 OVERVIEW

Also called the Chang Jiang meaning 'long river' the Yangtze River is the largest river in the People's Republic of China and the third longest river in the world. The river originates from the mountains of Quinghai Province on the Tibetan Plateau and flows 6 300 km west to the East China Sea with the outflow at Shanghai. Its catchment covers one-fifth of the land area in the People's Republic of China (PRC, 2004), with a basin size of 1 800 000 km^2 and mean discharge of 34 000 m^3/s (van der Leeden, Troise and Todd, 1990) (Table 23-1). The Yangtze River is accountable for 40 percent of China's freshwater resources, more than 70 percent of the country's rice production, 50 percent of its grain production and 70 percent of its fishery production. The Yangtze River's main channel flows through 12 provinces, namely Qinghai; Tibet, People's Republic of China; Yunnan; Sichuan; Guizhou; Chongqing; Hubei; Hunan; Jiangxi; Anhui; Jiangsu; and Shanghai (Chen *et al.,* 2009).

Table 23-1. Characteristics of the Yangtze River

Area of the river basin (km^2)	Percent area of the river in the country	Population of the river basin	Population density/km^2
1 789 503	100	387 115 949	211

Fish diversity

Freshwater fish diversity throughout monsoonal Asia is not completely known. The Yangtze River is home to 350 fish species, including the iconic and protected Giant Yangtze Sturgeon (Park *et al.,* 2003). In the Upper Yangtze above the Three Gorges Dam there are approximately 260 species belonging to 26 families, 19 of which are endemic. In the Middle Yangtze there are 230 species from 22 families and in the Lower Yangtze there are 33 families of which 30 are endemic (Abell *et al.,* 2008). The basin is the sole habitat of the critically endangered and thought to be extinct Chinese paddlefish and Yangtze sturgeon that is extinct in the middle and lower reaches of the river (Qiwei, 2010).

Fish introductions

A survey by the Ministry of Environmental Protection between 2006 and 2007 found that Amur sturgeon (*Acipenser schrenckii*), tench, channel catfish, black bullhead, largemouth bass, tilapia, large icefish, bluntnose black bream and other exotic fish had invaded the Upper Yangtze River.

23.2 FISHERIES OVERVIEW

The Yangtze River is described as the 'cradle for fisheries in China'. Its fishery yield accounts for about 70 percent of the freshwater fisheries production of the whole country. The Yangtze River has historically yielded economically important fish species, such as the major carp species (black carp, silver carp, grass carp, crucian carp, common carp and bighead carp), bronze gudgeon, Reeves shad, copper fish, tapertail anchovy and the Chinese eel (Chen *et al.,* 2004; Chen *et al.,* 2009). In the Lower Yangtze in the fisheries of Jiangsu Province, anchovy accounts for 50 percent of the catch, shad and eel 20 percent and major carps 30 percent. The catch from the Middle Yangtze accounts for 34 percent of the total catch; in the Lower Yangtze copper fish is the main commercial species accounting for 40 percent of the catch; the rest of the catch is made up by common carp and Chinese sturgeon. The Yangtze River is also an important production base for high quality freshwater aquaculture in the People's Republic of China (Chen *et al.,* 2009).

Fishing methods

Over 160 different types of fishing gear are used in the Yangtze River (Duan *et al.,* 2002) which include harmful gear such as mesh fyke nets, fyke nets, fish mazes, drop nets, damming nets and trap nets (Chen *et al.,* 2004).

Employment

Table 23-2 indicates the employment in fisheries according to the proportion of the province the river basin flows through. The table only indicates the number of full-time fishers, whereas for many fishing is not a full-time occupation; the number of part-time fishers as indicated by the China Agriculture Yearbook (2015) was substantial with around 1.62 million for the Yangtze River provinces. There were an estimated 2 400 fishery villages and 1.44 million fishery households within the basin in 2012 (China Agriculture Yearbook, 2014). Figures on gender employment in Yangtze River fisheries are unknown, but research suggests that in the People's Republic of China, 50 percent of the inland fisheries workforce are women (Mills *et al.,* 2011).

Table 23-22. Employment in Yangtze River Basin fishing activities

Province	Fishers	Fish farmers	Total
Qinghai	n/a	47	47
Tibet, People's Republic of China	17	n/a	17
Yunnan	3 753	23 349	27 102
Guizhou	4 937	28 263	33 200
Sichuan	24 095	300 102	324 197
Hubei	87 552	759 648	847 200
Chongqing	16 666	167 034	183 700
Hunan	53 940	352 379	406 319
Anhui	61 743	233 855	295 598
Jiangxi	59 329	308 948	368 277
Jiangsu	53 606	150 277	203 833
Shanghai	8 066	16 098	24 164
Total	**376 704**	**2 369 999**	**2 743 703**

Source: China Agriculture Yearbook (2014).

Estimated fisheries production

Table 23-3 indicates the estimated fisheries catch from the Yangtze River according to the percentage proportion of the area of each basin inside each province. Catches were reported from the 13 provinces that the Yangtze main channel flows through (Zhao and Shen, 2016). Systematic research on Yangtze fish production began in the 1950s and historically catches have shown large fluctuation from 400 000 tonnes in the 1950s, which declined by 50 percent in the 1980s with a low of around 100 000 tonnes in the 1990s and early 2000s (Chen *et al.,* 2004).

Table 23-3. Estimated fisheries production (tonnes) from the proportional area that the Yangtze River occupies in each province

River	Area/province	Catch estimate (tons)*	Year	Reference
Upper Yangtze	Tibet, People's Republic of China	69	2015	Zhao and Shen (2016)
	Yunnan	10 887		
	Guizhou	9 207		
Middle Yangtze	Sichuan	57 902		
	Hubei	212 786		
	Chongqing	14 679		
	Henan	31 932		
	Shanxi	1 893		
Lower Yangtze	Hunan	102 193		

River	Area/province	Catch estimate (tons)*	Year	Reference
	Anhui	309 359		
	Jiangxi	254 710		
	Jiangsu	102 749		
	Shanghai	0		
	Guangxi	4 597		
Total		**1 112 964**		

*Catch reported as tons but believed to be tonnes.

Status of the fisheries: catch trends

Statistics indicated a steady decline in the fisheries in the early 2000s but fish catches began to show an upward trend after 2005 (Lu *et al.,* 2016) owing to an increase in fishing effort, improvement in fishing technology and the number of fishers (Fu *et al.,* 2003). Almost all (97 percent) of the fishery yield came from below the Three Gorges Dam in the middle reach on the Yangtze River (Chen *et al.,* 2004). Structural changes in the fish community can be summarized as follows: decreases in the number of large individuals and an increase in small individuals in fish catches and a decline in the number of older individuals (Fu *et al.,* 2003).

Aquaculture

The People's Republic of China has a long history of aquaculture dating back more than 2 500 years. The proportion of fish production from fishing to the total production of freshwater fish has decreased while the contribution from aquaculture to total production increased from 68 percent in 1978 to 85 percent in 2000. In 2013, aquaculture production from the Yangtze River main channel provinces was around 5 million tonnes (China Agriculture Yearbook, 2014). About 20 species are economically important for aquaculture purposes; these include the major carp species, Japanese eel, Mozambique and Nile tilapia (FAO, 1983). Methods of aquaculture vary greatly ranging from wild fry caught and reared in ponds, semi-intensive fish culture in ponds, extensive culture in natural lakes, cages and pens to intensive fish culture (FAO, 1983).

23.3 THREATS TO THE FISHERIES

Overfishing

The use of harmful fishing gear, increased fishing effort and the number of fishers is contributing to overexploitation of the Yangtze River fisheries. At present, ten economically important species (major carps, gudgeon and catfish) are all overexploited. Historically, the fishery for the Reeves shad collapsed in 1975 after a decline in the mean size of individuals (Fang *et al.,* 2006). In addition, the Chinese paddlefish is classed as critically endangered, possibly extinct, by the IUCN due to historic overfishing and the presence of only two females recorded since 2002 (Qiwei, 2010). Catches of major carp from the Yangtze River began to decline before the construction of the Three Gorges Dam, but fell further from 80 percent of the river's catch to around 35 percent between the 1980s and 1990s (Chen *et al.,* 2004). However, a decline in carp production is not solely due to overfishing as cooler downstream temperatures from the Three Gorges Dam has led to retarded egg maturation and reduction in carp recruitment (Dudgeon *et al.,* 2006). Fishing levels at present are not sustainable for the maintenance of fish stocks, with many stocks threatened in the long term by increased overfishing (Chen *et al.,* 2002).

Habitat modification

Spawning migrations of the Chinese sturgeon and Chinese paddlefish were blocked initially by the Gezhouba Dam and subsequently by the Three Gorges Dam in 1981. The dams have obstructed breeding migrations, fragmented populations and degraded spawning sites. The abundance of these species has drastically declined, despite the re-establishment of spawning habitat below the Gezhouba Dam (Wei *et* *al.,* 1997). These species have declined by such an extent that they are classed as aquatic wildlife of First and Second Class Protection by the state, and catching of these species is strictly prohibited (Cui and Wang, 2006). Annual catches of major carp downstream of the Three Gorges Dam from 2003 to 2005 amounted to only 30 percent to 50 percent of that prior to the start of impoundment, with drifting eggs and larvae decreasing by 95 percent (Xie *et al.,* 2007). Indeed, reports have indicated that economically important carp have diminished by up to 90 percent since the completion of the Three Gorges Dam (Watts, 2011). The Chinese sucker formerly contributed more than 10 percent of the catch above the Three Gorges Dam. However, this species has been eradicated from the Lower Yangtze following the construction of the Gezhouba Dam (Chen *et al.,* 2004).

Water quality

River pollution is epidemic in the People's Republic of China. By the beginning of the millennium about 80 percent of the 50 000 km of major rivers was too polluted to sustain life (Dudgeon, 2011). Since 1950, there has been a 73 percent increase in pollution levels from cities that line the mainstream of the Yangtze River (WWF, 2005). The annual discharge of sewage and industrial waste into the river is approximately 25 billion tonnes. The river receives 42 percent of the country's total sewage discharge, and 45 percent of its industrial pollution (WWF, 2005). The Yangtze is now considered so dirty that the water is not fit for drinking. Heavy metal cadmium concentration from water in Hubei Province in the middle reaches was 160 times over applicable water standards, and from Henan Province was five times higher than background levels (Anid and Tschirley, 1998). Such high levels of pollution are also highly dangerous to fish populations. For instance, discharged concentrated sludge from a chemical plant into a tributary of the Upper Yangtze resulted in the loss of 481 tonnes of fish in 2002 (Dong *et al.,* 2006). In addition, the river water in Chongqing Province induced the mutation of fish somatocytes and influenced fish genetic quality (He *et al.,* 1998).

23.4 EQUIVALENT FOOD REPLACEMENT

The Yangtze Basin fishery yield accounts for about 70 percent of the freshwater fisheries for the whole country (Chen *et al.,* 2009). Despite this, both capture fisheries and aquaculture are threatened by severe water pollution and the impact from hydropower construction. Given that the population of the basin is only likely to increase, leading to increased pollution problems, combined with further hydropower construction planned for the basin, the fishery resources are highly threatened. Equivalent food replacement estimates were established for a 50 percent loss in the estimated fisheries production (Table 23-3) and replacement with livestock (beef, pork, chicken), crops (rice) and aquaculture (common carp and tilapia).

Table 23-4. Food production (tonnes), water (km^3), land (km^2) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km^3 (percentage of agricultural water use)	Land required to replace fisheries in km^2 (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Common carp	336 270 (10.6)	1.01 (0.3)	56 045 (3.1)	
Tilapia	329 228 (19.4)	0.98 (0.3)	14 965 (0.8)	0.09
Beef	345 508 (5.3)	5.32 (1.4)	39 866 (3.8)	21.6
Pork	180 697 (0.3)	1.08 (0.3)	24 640 (2.3)	0.1
Chicken	569 072 (4.4)	2.46 (0.7)	15 270 (1.4)	1.4
Rice	483 711 (0.2)	1.07 (0.3)	1 061 (0.03)	0.06

Energy replacement (Table 23-4)

The People's Republic of China is one of the world's largest aquaculture producers and replacement of kilojoules from capture fisheries with common carp and tilapia aquaculture would require an increase in production equivalent to 10.6 percent and 19.4 percent of current production (farmed common carp and tilapia production in 2015 was 3.17 million tonnes and 1.70 million tonnes, respectively). Rice production would be required to increase 483 711 tonnes to replace kilojoules from capture fisheries. However, due to the large amount of rice produced in China, the replacement amount is small when compared to annual production (0.2 percent of current production in 2014, which was 208 million tonnes).

Water demand (Table 23-4)

Beef production would require the largest increase in freshwater use, equivalent to 1.4 percent of agricultural water use in China (agricultural water use in China in 2013 was 392.2 km^3). Chicken production would require roughly half the amount of water that beef production would require, equivalent to 0.7 percent of agricultural water use. The remaining replacement food sources require similar amounts of water, equivalent to 0.3 percent of water withdrawals for agriculture.

Land requirements (Table 23-4)

Farmed common carp production would require the largest amount of land to replace capture fisheries, equivalent to 3.1 percent of the total Yangtze River Basin area (Table 23-4). Beef production would require the second largest land conversion, equivalent to 3.8 percent of the total pastureland in China (pastureland area in 2014 was 1.06 million km^2). Rice production would require the smallest land conversion, equivalent to 0.03 percent of arable land (arable land area in 2014 was 3.92 million km^2).

Greenhouse gas emissions (Table 23-4)

Estimated carbon emissions from 50 percent capture fisheries from the Yangtze River Basin were 1.4 million tonnes. Additional carbon emissions from replacement food sources would be highest from beef production with an additional 21.6 million tonnes of carbon emissions. Chicken would have additional emissions of 1.4 million tonnes and farmed tilapia and pork production would result in additional emissions of 0.09 million tonnes and 0.1 million tonnes, respectively.

23.5 FISHERIES MANAGEMENT

At present, national law, legislation and regulations have been established for the conservation of the Yangtze River fishery resources. The most fundamental law comes from The Law of the People's Republic of China on Fisheries, related to which are Regulations on the Management of Yangtze Fishery Resources and governance by the Yangtze Fishery Resources Management Committee (Chen *et al.,* 2009).

National management strategies

Closed seasons

The main management thrust for the Yangtze River fishery is through the basin-wide fishing ban, which was first implemented as a trial in 2001. In 2003 it was comprehensively put into effect along the main channel of the Yangtze. The fishing ban lasts from February to April in the Upper Yangtze, and from April to June in the Lower Yangtze (Xiao, 2010). This type of management has promoted the conservation and restoration of fish resources and protects migrating fish during the breeding season, but to promote the health development of the fishery, closed seasons should be extended to the important tributaries of the Yangtze (Chen *et al.,* 2009).

Nature reserves

At present Chinese fisheries management has established nine national and provincial nature reserves and 30 municipal and county nature reserves (Xiao, 2010), the total area of which accounts for 6 percent of the basin area (Chen *et al.,* 2009). Two of the nature reserves are designated areas for the protection of Chinese sturgeon at the provincial level (Chen *et al.,* 2009). The primary aim of the nature reserves is to protect populations of endangered species and their habitats. Protected species include dolphin, Chinese sturgeon, giant salamander and other aquatic life unique to the Yangtze Basin (Chen *et al.,* 2009).

International management strategies

The Yangtze Project – Restoration of the Yangtze is part of a joint enterprise between the WWF and the Chinese Government; this project aims to restore floodplain wetlands in the middle Yangtze region to restore wildlife habitat, reduce risk of floods and improve the livelihoods of local people (Schuyt, 2005). Since 2002, connections between 11 lakes and the Yangtze River have been restored and the WWF has demonstrated new sustainable agricultural practices to reduce agricultural pollution (Wong *et al.,* 2007).

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24 YELLOW RIVER (HUANG HE)

24.1 OVERVIEW

The Yellow River, otherwise known as the Huang He (Table 24-1), is the second longest river in the People's Republic of China after the Yangtze, covering a length of 5 464 km. The Yellow River originates in the Bayan Har Mountains in the Eastern Plateau of Tibet, People's Republic of China and flows into the Gulf of Chihli on the North Pacific Coast. The Yellow River carries the largest sediment load of any river in the world (34 kg/m^3) and is known as the Yellow River after the fine loess sediment that it carries. The river is divided into three sections. The upper course, from its source 1 165 km near the city of Lanzhou and the middle course covering 2 900 km until it reaches the Wei River where it turns east. In the lower course the river broadens out and flows for 700 km to the delta with the Pacific Ocean. The river flows through six provinces and two autonomous regions in the People's Republic of China. The Yellow River receives water from many tributaries, the largest of which are the Fen and Wei rivers.

Table 24-1. Characteristics of the Yellow River

Area of the river basin (km^2)	Percent area of the river in the country	Population of the river basin	Population density/km^2
832 147	100	137 613 335	165

Fish diversity

According to FishBase, the Yellow River contains 58 species of which most are cyprinids (34 species). The Nemacheilidae family is also prominent with 15 species including the Tibetan stone loach (*Triplophysa stoliczkai*) (FishBase, 2017). The Yellow River is home to small populations of the critically endangered Chinese paddlefish (*Psephurus gladius*) and Yangtze sturgeon (*Acipenser dabryanus*) (IUCN, 2016). The Chinese Ministry of Agriculture has declared around 30 percent of fish species within the river basin extinct due to anthropogenic pressures on the system (Handwerk, 2007).

Fish introductions

The only documented introduction into the Yellow River is rainbow trout (*Oncorhynchus mykiss*), introduced into the Longyangxia Reservoir in the Upper Yellow River for aquaculture purposes (Edwards, 1992).

24.2 FISHERIES OVERVIEW

The Yellow River supports two regional fisheries in the Middle and Upper Yellow River. Historically, the Yellow River fishery consisted of wooden boats and floating nets in the headwaters in Qinghai Province and was active from April to October. The most important species in this fishery were *Gymnocypris eckloni*, *Gymnocypris pachychilus*, *Platypharodon extremus*, *Schizopygopsis pylzovi* and the stoneloach species *Triplophysa siluroides*, with *P. extremus* accounting for more than 80 percent of the catch. The fisheries on the Gyaring and Ngoring lakes in the Upper Yellow River opened in the 1960s and have persisted despite difficulties in transport and marketing. Fisheries in western regions of the People's Republic of China are considerably smaller than in other regions due to the small markets, poor economic conditions and tendency of local populations to consume mutton and beef. In Tibet, People's Republic of China, people are reluctant to eat fish, which have religious significance (Walker and Yang, 1999).

Fishing methods

River fisheries in the Upper Yellow River use small wooden boats and floating nets. The lake fishery in the Upper Yellow River uses small boats, seine nets and gillnets (Walker and Yang, 1999).

Employment

Table 24-2 indicates employment in fisheries in the provinces that the main river channel flows through, according to the proportion of the basin in each province. The table only indicates the number of full-time fishers, whereas fishing activities in the upper reaches are mainly artisanal and are conducted on a part-time basis (Walker and Yang, 1999). The number of part-time fishers indicated by the China Agriculture Yearbook (2014) was high with 243 158 part-time fishers.

Table 24-2. Employment in Yellow River Basin fishing activities

Province	Fishers	Fish farmers	Total
Qinghai	76	57	133
Gansu	1 020	994	1 964
Ningxia	10 706	9 483	20 189
Shaanxi	19 547	16 634	36 181
Shanxi	2 051	1 726	3 777
Inner Mongolia	2 374	1 313	3 687
Henan	50 208	37 059	87 267
Shandong	95 670	46 235	141 905
Total	**181 652**	**114 726**	**296 378**

Source: China Agriculture Yearbook (2014).

Estimated fisheries production

Table 24-3 indicates the estimated fisheries catch from the Yellow River according to the proportional area of each province that the basin occupies (Zhao and Shen, 2016). Water pollution levels in some of the middle and lower reaches of the Yellow River were considered above levels toxic to fish; therefore, the fish catch estimate is likely an overestimation for the lower Yellow River. However, no other estimates of fishery yield from the Yellow River, apart from the Upper Yellow River, were available.

Table 24-3. Production estimates for the Yellow River

<table>
<tr><th>River</th><th>Area/province</th><th>Catch estimate (tons)*</th><th>Year</th><th>Reference</th></tr>
<tr><td rowspan="2">Upper Huang He</td><td>Qinghai</td><td>1 500</td><td>1983</td><td>Wang (1987)</td></tr>
<tr><td>Gansu</td><td>n/a</td><td>n/a</td><td>n/a</td></tr>
<tr><td rowspan="5">Middle Huang He</td><td>Ningxia</td><td>230</td><td rowspan="7">2015</td><td rowspan="7">Zhao and Shen (2016)</td></tr>
<tr><td>Shaanxi</td><td>3 491</td></tr>
<tr><td>Shanxi</td><td>699</td></tr>
<tr><td>Inner Mongolia</td><td>4 041</td></tr>
<tr><td>Sichuan</td><td>2 125</td></tr>
<tr><td rowspan="2">Lower Huang He</td><td>Henan</td><td>10 593</td></tr>
<tr><td>Shandong</td><td>17 798</td></tr>
<tr><td>Total</td><td></td><td>40 476</td><td></td><td></td></tr>
</table>

*Catch reported as tons but believed to be tonnes.

Status of the fisheries: catch trends

Fisheries in the Upper Yellow River mainly consist of fish catches from the Gyaring and Ngoring lakes, where catches were estimated at 1 500 tonnes in the early 1980s; there are no more recent estimates, so the current state of the fishery is difficult to assess. River fisheries in the Upper Yellow River yielded an average annual production of 100 tonnes from 1958 to 1983, but productivity has since fallen with the most recent annual average yield of 17 tonnes in the early 1990s (Walker and Yang, 1999).

Aquaculture

Generally, in the People's Republic of China the inland fishery yield through aquaculture is higher than the yield through capture fisheries. In the Upper Yellow River rainbow trout are cultured in cages in the Longyangxia Reservoir (Edwards, 1992). Generally, water quality in the lower reaches of the Yellow River has been considered too polluted to support aquaculture activities. But semi-intensive field pond systems in the saline–alkaline habitat of the Yellow River plain in the lower reaches have existed since the 1990s (Zhong, Wang and Wu 1997). However, fish farming in the Yellow River Delta is causing increasing environmental problems of ground subsidence, at rates nearly 100 times faster than the global average (up to 25 cm a year). Water extraction from the delta for fish farms has also been causing severe erosion of the delta, affecting coastal stability and coastline communities (Higgins *et al.,* 2013).

24.3 THREATS TO THE FISHERIES

Climate change

Climate change within the Yellow River is predicted to be drastic, with changes to daily mean temperature, daily precipitation and evaporation (UNESCO, 2011). Temperatures throughout the basin are predicted to increase 1.4 °C to 3 °C by 2050. Precipitation and evaporation are also predicted to increase, which will only increase the water shortage within the basin of between 9.7 billion m^3 to 13.7 billion m^3 by 2050. Glacial thawing and shrinking will lead to a gradual decrease in glacial runoff (UNESCO, 2011).

Water quality

River pollution in the Yellow River is endemic. In Shanxi Province in the Middle Yellow River the mining industry had polluted the surface water to such an extent that the water was unsuitable for any uses (Ongley, 2000). Also, in 2008 severe pollution made one-third of the Yellow River unsuitable for drinking, agriculture and industry (Branigan, 2008). Most (71 percent) of the river length is highly polluted, almost double that of the Chinese average (Ongley, 2000). The major pollution indicators are chemical oxygen demand, ammonia, nitrogen and biochemical oxygen demand (Ministry of Environmental Protection, 2015).

In the downstream delta regions, there is serious surface and groundwater pollution from industrial effluents, oil and gas extraction and refining activities. According to the Ministry of Environmental Protection (2015) water quality had shown no improvement over the previous few years. In the mainstream, 34.7 percent of the monitored areas met Grade III standards (a rise of 15 percent) (potentially potable water if appropriate treatment measures are taken) and 7.7 percent achieved Grade IV (water only appropriate for agricultural and industrial use).

The tributaries of the Yellow River were more polluted than the main channel. None of the tributaries met the clean water standards; 13.9 percent of the river's length was classed as Grade IV, 13.9 percent as Grade V (water only suited for agricultural and industrial use) and 22.2 percent failed Grade V and was not usable. Water pollution within the basin extends into the delta, coastal and marine environment and severely impacts marine life and commercial fisheries (Ongley, 2000).

Habitat modification

There are 27 large dams and reservoirs with individual capacity exceeding 0.1 km^3 throughout the basin, four of which are on the mainstream and contribute towards water regulation and sediment retention (Wang *et al.,* 2006). The construction of large dams along the mainstream and major tributaries has significantly changed the natural flow regime of the river. In recent years, zero flow conditions have occurred in the Lower Yellow River from increasing water consumption, climate change and human activities (Xu, 2002). The sediment load of the Yellow River decreased sharply from 1.08 Gt/year to 0.15 Gt/year from 2000 to 2005, because of the construction of the Liujiaxia and Longyangxia reservoirs in the upper reaches (Wang *et al.,* 2007). Reductions in nutrient and sediment load and water flow are detrimental to fisheries production, and the increasing human demand for water resources further strains the water needs to maintain the ecological environment (Yang *et al.,* 2008).

24.4 EQUIVALENT FOOD REPLACEMENT

Although the scale of inland fisheries within the Yellow River is relatively unknown, the scale of water quality problems within the basin suggests an estimated 30 percent of the fish species are extinct within the basin. Equivalent food replacement was estimated for a 50 percent loss in the total fisheries production from Table 24-3. Replacement food items consist of livestock, (beef, pork and chicken), crops (rice) and aquaculture (common carp and tilapia).

Table 24-4. Food production (tonnes), water (million m³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Common carp	12 229 (0.4)	38.2 (0.01)	2 038 (0.2)	
Tilapia	11 973 (0.7)	35.8 (0.01)	544 (0.07)	0.003
Beef	12 565 (0.2)	193.7 (0.05)	1 449 (0.2)	0.79
Pork	6 571 (0.01)	39.5 (0.01)	896 (0.08)	0.004
Chicken	20 595 (0.2)	89.5 (0.02)	555 (0.05)	0.05
Rice	17 591 (0.008)	39.2 (0.01)	39 (0.001)	0.002

Energy replacement (Table 24-4)

Replacement of kilojoules of protein with farmed common carp and farmed tilapia production would require increased production, equivalent to 0.4 percent and 0.7 percent of current aquaculture production, respectively (common carp production was 3.36 million tonnes, and tilapia production was 1.78 million tonnes in 2015). Pork would require the smallest increase in production to replace kilojoules from capture fisheries, but due to the large amount of pork produced in China, this is equivalent to 0.01 percent of current production (2014 production was 55.4 million tonnes). Rice production would be required to increase to replace capture fisheries, but as rice production is high in China, the replacement amount is small compared to current production (0.008 percent of current production).

Water demand (Table 24-4)

Beef production would require the largest increase in freshwater use, equivalent to 0.05 percent of the total agricultural water abstractions in China (agricultural water use in 2013 was 392.2 km³). Chicken production would require roughly half the water demand required by beef, equivalent to 0.02 percent of agricultural water abstractions. The remaining replacement food sources require similar amounts of water for replacement, equivalent to ≤0.01 percent of agricultural water abstractions.

Land requirements (Table 24-4)

Farmed common carp production would require a large amount of land to replace capture fisheries, equivalent to 0.2 percent of the Yellow River Basin area. However, with improvement of water quality within the basin there is room to substantially expand aquaculture practices within the basin. Beef production would require the second largest land conversion, equivalent to 0.2 percent of pastureland in China (the 2014 pastureland total was 3 928 340 km²). Rice production would require the smallest land conversion of 39 km², equivalent to 0.001 percent of arable land within China (arable land in 2014 was 1 062 977 km²).

Greenhouse gas emissions (Table 24-4)

Estimated greenhouse emissions from a 50 percent loss to the Yellow River capture fisheries were 68 721 tonnes. Additional carbon emissions from replacement food sources would be highest for replacement with beef with an additional 0.79 million tonnes. Chicken production would require 49 019 tonnes, pork 3 634 tonnes, farmed tilapia 3 115 tonnes and rice 2 017 tonnes.

24.5 FISHERIES MANAGEMENT

Laws governing water management in the People's Republic of China are formed at national, local and provincial levels, unfortunately there are no laws governing the fisheries of the Yellow River.

National management strategies

The Ministry for Water Resources is responsible for the quality of water at the national level and the Yellow River Conservancy Commission (YRCC) has the primary responsibility for water management in the Yellow River. This responsibility includes sediment, drought, water quality and environmental water management. The Ministry of Water Resources coordinates basin-wide through the YRCC and exercises enforcement of standards through provincial governments. The Yellow River Law, introduced in 2002, aimed to overcome the lack of legislation, enforcement and regulations for the Yellow River (Zhuang, Xu and Chen 2015). The Yellow River Law follows the principles of the Water Law but also reflects the special characteristics of the Yellow River Basin. To improve the general water quality of the river basin, fisheries within the basin may improve although this may take considerable time.

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25 AMUR RIVER

25.1 OVERVIEW

Also known as the Heilongjiang in the People's Republic of China, the Amur River (Table 25-1) is the largest undammed river in the eastern hemisphere. The farthest sources of the Amur River are in the Khentii Mountain Range of northeastern Mongolia, where the Shilka and Argun rivers join it about 2 824 km from the river mouth, before it empties into the Sea of Okhotsk. The river is primarily fed by monsoon rains and has an average flow of 1 800 m^3/s; during the monsoon rains the river fluctuates by as much as 9 m to 19 m. Melting snow and summer rains commonly result in catastrophic flooding. The major tributaries of the Amur River are the Shilka, Zeya, Bureye, Argun, Songhua and Ussuri watercourses (Bogutskaya and Hales, 2017).

Table 25-1. Characteristics of the Amur River Basin

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
Russian Federation	1 008 029	48.32	3 659 475	4
Mongolia	189 481	9.08	163 062	0.8
People's Republic of China	888 418	42.59	63 497 673	71
Democratic People's Republic of Korea	60	0.002	1 380	23
Total	**2 085 989**	**100**	**67 321 591**	**24.7**

Fish diversity

According to FishBase the Amur River contains 150 species, the most abundant family being Cyprinidae with 66 species, which include major carp, and gudgeon species. There are six endemic species in the Amur River: the Amur sturgeon (*Acipenser schrenckii*), Herzensteins's catfish (*Tachysurus herzensteini*) and four species from the Cobitidae family*, Iksookima koreensis, I. hugowolfeldi, I. longicorpa* and *I. pumila* (FishBase, 2017).

There is a similar number of species present in the Argun River, except that this stretch of river contains the Amur sturgeon, two species of gudgeon (*Gobio soldatovi tungussicus* and *Gobiobiota*), yellowfin (*Xenocypris*) and sharpbelly (*Hemiculter leucisculus*) which are not found in the Amur River (FishBase, 2017).

Fish introductions

According to FishBase there have been four documented introductions into the Amur River: the goldfish (*Carassius auratus*), bighead carp (*Hypophthalmichthys nobilis*), stone moroko (*Pseudorasbora parva*) and the pikeperch (*Sander lucioperca*) (FishBase, 2017). However, according to Novomodny, Sharov and Zolotukhin (2004) at least 24 species have been introduced to the Amur River Basin, however, six of the introduced species are thought to have disappeared.

25.2 FISHERIES OVERVIEW

Fishing is one of the chief economic activities in the Amur River. There are about 25 to 30 species of commercial value. These consist of Chinese perch (*Siniperca chuatsi*), white Amur (*Mylopharyngodon piceus*), burbot (*Lota lota*) and also salmonid species – chum (*Oncorhynchus keta*), pink (*O. gorbuscha*), masu (*O. masu*), coho (*O. kisutsch*) and Chinook salmon (*O. tschawytscha*). The steelhead (*Parasalmo mykiss*), Siberian taimen (*Hucho taimen*), lenoks (*Brachymystax lenok* and *Brachymystax tumensis*) and Dolly Varden trout (*Salvelinus malma*) are all popular in commercial, sport or subsistence fishing

(Novomodny, Sharov and Zolotukhin, 2004). One of the most important and valuable commercial fisheries is one that harvests sturgeon, principally Amur sturgeon and kaluga (*Huso dauricus*). Commercial fishing in the People's Republic of China began in the 1950s and harvested sturgeon were mainly for local consumption, but after the 1980s, this expanded in intensity (Wang and Chang, 2006). Conversely, in the Russian Federation, sturgeon has been fished commercially for more than 100 years, and females have been harvested for their caviar or roe (Vaisman and Raymakers, 2001). However, catches of sturgeon declined significantly during the twentieth century, with the main threat to both Amur and kaluga sturgeon being overexploitation for trade. Commercial fishing for sturgeon is permitted in the People's Republic of China under strict quotas (Wang and Chang, 2006), but there has been no commercial fishery for sturgeon in the Russian Federation since 1984 and as such illegal fishing for sturgeon is widespread. 'Test fishing' of sturgeon species was introduced in 1984; this allows the harvest of Amur River sturgeon for non-commercial purposes. It is believed that test-fishing quotas are used by private firms to circumvent the bans on commercial fishing (Vaisman and Fomenko, 2006).

Fishing methods

In the People's Republic of China, traditional sturgeon fishing methods formerly consisted of pull nets, longlines and big hooks and two- or three-layer gillnets. However, the Chinese Government banned the use of traditional gear to help reduce damage to the sturgeon stocks, and currently only temporary, or drifting gear are allowed (Wang and Chang, 2006). Subsistence fishing uses fine-meshed nets that are used to catch fingerlings, also the use of explosives and poisons is common (Fisheries Bureau of the Heilongjiang Province, 2017).

Fish trade

In the People's Republic of China, the roe from both Amur sturgeon and kaluga is processed for export and the meat is consumed domestically (Wang and Chang, 2006). In accordance with regulations set by the Convention on International Trade in Endangered Species (CITES), Appendix II), export quotas for sturgeon caviar are set, with previous quotas at around 5.94 tonnes in 2001, but for the 2004–2005 period, the export quota was zero (Wang and Chang, 2006). In Russian Federation, selling sturgeon products is very profitable as expenses and taxes are only paid by legal sales, hence illegal sales bring pure profits to poachers. TRAFFIC Europe–Russia established that on the world market, the price of black caviar may reach USD 3 500/kg (TRAFFIC, 2002). Illegal sturgeon catches are worth an estimated USD 9 million to USD 11 million annually (Fisheries Bureau of the Heilongjiang Province, 2017).

Employment

Estimates for the involvement in legal or illegal sturgeon fishing activities on the Amur River in Russian Federation are not known. The commercial chum salmon fishery had an average 230 fishers from 92 fishing boats from 1996 to 2000 (Novomodny, Sharov and Zolotukhin, 2004). But in the People's Republic of China, the Heilongjiang Provincial Government issued 1 850 fishing licences to catch sturgeon, a fall from 2 248 licences in 1991 (Wang and Chang, 2006).

Estimated fisheries production

Estimated fisheries production from the Amur River are outlined in Table 25-2. As the fishery statistics from the People's Republic of China are reported by province, the catch values in Table 25-2 represent the proportional area that the Amur Basin occupies in each province (Zhao and Shen, 2016). Other than the sturgeon and salmonid commercial fisheries there is little information regarding the fish catch of other species in the Amur River. Average catch between 1987 and 1991 was 322.2 tonnes, and official sturgeon catches in the People's Republic of China in 2002 were estimated at 140 tonnes, a fall from peak catches of 452 tonnes in 1982 (Wang and Chang, 2006). The Chinese portion of Heilongjiang was considered by Wang and Chang (2006) as an underdeveloped region where fisheries data have not been collected regularly and are usually scattered and insufficient for analysis.

In Russian Federation, the ban on commercial fishing for sturgeon appeared to have had no effect on the annual harvest levels and catches had increased since the ban from 64.1 tonnes in 1983 (the year before the ban) to peak catches of 135.9 tonnes in 1991. Catches have declined since then to only 1 tonne in 2018 (FAO, forthcoming). However, this figure is an underestimation of actual sturgeon catches, due to the level of illegal fishing from the Russian portion of the Amur Basin. Illegal fishing exceeds legal catches by three or four times, and illegal catches in the Lower Amur are estimated at 750 tonnes. This far exceeds the 100 tonnes catch quota that is allowed for scientific purposes (Novomodny, Sharov and Zolotukhin, 2004).

Salmon fishery production declined from 93 500 tonnes in the early 1990s to 30 419 tonnes in 2018 (FAO, forthcoming) due to a drop in commercial fishing, in which many people lost their jobs and began subsistence fishing to support their livelihoods. These figures are not reflected in Table 25-2 as subsistence fishing catches are not recorded, but were estimated at around 9 000 tonnes from local fishing (Novomodny, Sharov and Zolotukhin, 2004; Vaisman and Fomenko, 2006).

Table 25-2. Estimated fisheries production from the Amur River

Country	Province/area	Catch estimate (tonnes)	Year	Reference
People's Republic of China	Heilongjiang	50 696	2015	Zhao and Shen (2016)
	Jilin	14 694		
	Inner Mongolia	8 707		
Russian Federation		6 300	2018	FAO (forthcoming)
Total		**80 397**		

Status of the fisheries: catch trends

Historical catch data indicate a significant decline in sturgeon stocks; catches fell by an average of 139 tonnes in the 1940s, and continued to fall to just 31.2 tonnes of kaluga and Amur sturgeon in 2005 representing a 91 percent fall in sturgeon catches from the start of the century (Svirskii, 1971; Krykhtin and Svirskii, 1997; Novomodny, Sharov and Zolotukhin, 2004). The primary cause of decline in recent decades has mainly been because of overfishing in the 1980s and an unprecedented level of illegal fishing. The overall level of poaching in the People's Republic of China is much lower than in Russian Federation (Novomodny, Sharov and Zolotukhin, 2004).

No populations of salmon are known to have become extinct in the Amur River, but during the twentieth century all populations of salmonids declined significantly. Chum salmon has disappeared completely in the People's Republic of China from the Upper and Middle Amur; currently commercial fishing is only permitted in the estuary (Novomodny, Sharov and Zolotukhin, 2004). After reaching catch levels of 93 000 tonnes in the early 1990s, the commercial catch of chum salmon collapsed to 3 000 tonnes by the end of 1993 (Novomodny, Sharov and Zolotukhin, 2004).

Aquaculture

In Russian Federation, captive-breeding of sturgeon is carried out at two hatcheries within the basin, the Amursk hatchery and Novoamursky hatchery. In 2003, 187 000 fingerlings and up to 1 500 marked one-year old sturgeon were released. The Novoamursky hatchery, released 87 000 fingerlings in 2003 and is known to have released up to 1 million unconditioned fingerlings (Novomodny, Sharov and Zolotukhin, 2004; Vaisman and Fomenko, 2006).

In the People's Republic of China, hybridization between Amur sturgeon and kaluga was successfully carried out, but each species is also cultured separately (Wei *et al.,* 2004). In 2001, 20 000 kaluga and 130 000 Amur sturgeon fingerlings were released into the Amur River along with 3 000 Amur sturgeon juveniles (≥1.5 kg) (Wei *et al.,* 2004). However, even though artificial reproduction of sturgeon is conducted in Russian Federation and China, there is no coordination between the countries and no assessment on the success of releases has been conducted. As such, the influence of cultured sturgeon on wild populations is unknown and could be causing a serious threat to the wild population (Novomodny, Sharov and Zolotukhin, 2004; Wei *et al.,* 2004).

Recreational fishing

Commercial catches of taimen (*Huso tamien*) have been prohibited in the central and lower areas of the Amur River Watershed as the species is a valuable food fish for local populations (Zolotukhin, 2013).

25.3 THREATS TO THE FISHERIES

Overexploitation and illegal unregulated fishing

About one-quarter of the mature sturgeon population is caught every year from the Amur River. Female sturgeon are harvested for caviar and many of the sturgeon caught are first-time spawners. Amur sturgeon and kaluga take at least 10 and 16 years respectively to mature, therefore neither species has the reproductive capacity to overcome high levels of exploitation, which makes them susceptible to extinction. Sturgeons are not the only species threatened in the Amur River Basin. The yellowcheek, black carp, black Amur bream, small-scale carp, Soldatov's catfish and Chinese perch are all listed in the Red Book of the Russian Federation as threatened species (Novomodny, Sharov and Zolotukhin, 2004). In addition, the range of salmonid species within the basin has significantly declined due to overfishing; currently salmonid populations are only present in the Lower Amur River (Novomodny, Sharov and Zolotukhin, 2004).

Illegal fishing and poaching are endemic in the Amur River. For instance, in 2000, the quantity of caviar that received veterinary certification (36 700 kg) was far greater than the amount that could have been caught legally (6 185 kg). Corruption among officials and fish inspectors is widespread, with poorly paid inspectors bribed to ignore poaching activities. Also, much of the illegal catch is 'legalized' or laundered by placing illegal catch under the care of law enforcement officers where it can be passed off as legal catch (Vaisman and Fomenko, 2006). Generally, law enforcement is weak and legislation does not act as a deterrent; as such even a ban on sturgeon fishing has not prevented overfishing (Novomodny, Sharov and Zolotukhin, 2004).

Water quality

Both the People's Republic of China and Russian Federation have been unable to tackle the increasing pollution problems in the Amur River Basin. There is an absence of transboundary pollution prevention standards. Wastes from uranium and gold mines contaminate the river along with hydrocarbons, heavy metal and organic waste. The Middle Argun and Songhua rivers are considered two of the most polluted portions of the basin, with most of pollutants accumulating from China. Since the early 1990s water quality on the Argun River has deteriorated and a lack of dissolved oxygen has caused repeated die-offs of fish in winter. Microbial analysis showed that fish in the main stem of the Amur River, especially downstream of the Songhua River, were highly contaminated with bacteria and did not meet existing epidemiological standards for human consumption (Simonov and Dahmer, 2008).

25.4 FISHERIES MANAGEMENT

International management

In 1997, all species belonging to the Order Acipenseriformes that were not already listed on CITES, were listed in Appendix II of CITES, including Amur sturgeon and kaluga (Wang and Chang, 2006).

Transboundary management

The People's Republic of China and the Russian Federation signed a protocol on the regulation, protection and propagation of fishery resources in the border area between China and the Russian Federation along the Heilongjiang (Amur) River and the Wusuli River. As part of the protocol, both governments aimed to assure that the Amur sturgeon and kaluga were the main species for protection, restoration and propagation. Size limits were imposed for Amur sturgeon (minimum length 1 m and above 4 kg) and kaluga (minimum length 2 m and above 65 kg). Seasonal restrictions on fishing were imposed between 11 June and 20 July and some parts of the Amur River were established as 'closed fishing zones' in order to propagate and protect juvenile fish (Wang and Chang, 2006).

National management

In the People's Republic of China, the provincial government of Heilongjiang created a designated section of the mainstream covering an area over 5 km long as a closed fishing area. In addition, the provincial government used the same size restrictions for Amur sturgeon and kaluga mentioned above. Special licences and catch quotas (347 tonnes) were created to fish for sturgeon and the number of licences was limited to 1 886. Chinese and Russian management measures also address conservation and replenishment of sturgeon stocks via culture and release practices. About 300 000 sturgeon juveniles have been raised artificially, but it will take ten years for cultured sturgeon to mature before caviar can be produced (Wang and Chang, 2006).

In Russian Federation a the Department for Protection, Restocking and Use of Aquatic Biological Resources under the Ministry of Agriculture has been responsible for the management of sturgeon species. Commercial fishing for sturgeon species in Russian Federation has been illegal since 1984, but 'test fishing' for non-commercial purposes or research was introduced after the ban. However, test fishing is believed to be used for circumventing the commercial fishing bans, as private firms that buy test fishing quotas catch far more than their allowed quota. As such, it is perceived that stocks are being preserved, but in reality, commercial fishing continues (Novomodny, Sharov and Zolotukhin, 2004).

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26 BRAHMAPUTRA RIVER

26.1 OVERVIEW

The Brahmaputra is one of the world's largest rivers (Table 26-1). Its source is in the Kailas Range of the Himalayas in the People's Republic of China. The river traverses 1 625 km in Tibet, People's Republic of China eastwards and flows 918 km through India and then 337 km through Bangladesh and into the Bay of Bengal through a joint channel with the Ganges. Over its course, it is fed by 58 tributaries – 22 are in Tibet, People's Republic of China; 33 are in India; and 3 are in Bangladesh – giving the Brahmaputra a combined length of 4 023 km (Chandra and Bhattacharyya, 2016). The Brahmaputra is fed by glacial snowmelt in the Himalayas and has an annual average discharge of 260 km^3 (FAO, 2016). The Brahmaputra supports numerous floodplain lakes, locally known as *beels* (Boruah and Biswas, 2002). The Brahmaputra system supports four major types of fish habitat: fast-flowing river with shallow gravel bed; upstream pools in the deeper parts of the river; *beels* that are either temporarily or permanently connected with the main river channel; and lastly the open river, which hosts a variety of fish species (Boruah and Biswas, 2002).

Table 26-1. Characteristics of the Brahmaputra River Basin

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
China (Tibet, PRC)	270 000	50	1 921 629	6
India	195 000	36	603 216 193	619
Bangladesh	39 100	7	148 425 273	1 229
Bhutan	38 400	7	817 709	22
Total	**543 400**	**100**	**754 380 804**	**469**

Fish diversity

According to FishBase the Brahmaputra River contains 134 species (Table 26-2), the most abundant families being Cyprinidae (39 species) and Nemancheilidae (25 species). There are five endemic species, all from the Nemancheilidae family. *Beels* are feeding and breeding grounds for many riverine fish species, but also harbour a residential fish population of air-breathing forms such as snakehead (*Channa*), *Clarius* and *Anabus.* The open water systems are home to the Ganges river dolphin, which is classed as endangered by the IUCN (Boruah and Biswas, 2002; Smith and Braulik, 2012).

The Central Fisheries Research Institute (CFRI) recorded the occurrence of common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*) and silver carp (*Hypophthalmichthys moltrix*) in the Brahmaputra tributaries, however none of these species have established fully in the main river (Vass and Bhattacharjya, 2008).

Table 26-2. Fish diversity in the Brahmaputra River Basin

River	Total diversity	Endemic	Introduced
Brahmaputra	134	5	3

Sources: Vass and Bhattacharjya, (2008); FishBase, (2017)

26.2 FISHERIES OVERVIEW

Riverine fisheries are of great importance in tropical regions as they provide food and nutrition to millions of people and support their livelihoods (Chandra and Bhattacharjya, 2016). Fisheries conducted in the Brahmaputra River differ between countries, but generally the river supports commercial and subsistence fisheries of various scales. Category-wise, professional, seasonal and subsistence fishers operate in the river (Ahmed *et al.,* 2013). Professional fishers conduct fishing all year round for their livelihood and income; seasonal fishers undertake fishing during part of the year to supplement their income; subsistence fishers mainly fish for household consumption and consume most of their catch (Ahmed *et al.,* 2013). Generally, the intensity of fishing is closely associated with the flood regime of the river, with peak fishing intensity just before and after every flood (Biswas and Boruah, 2000). Around 41 species have commercial significance – mainly Indian major carp species (rui, catla, mirgal carp and orangefin labeo), catfish (*Wallago attu*, giant river catfish and Pangasius catfish), knifefish (*Chitala chitala*) and hilsa (*Tenualosa ilisha*) (Bhattacharjya, Bhaumik and Sharma, 2017). In the Upper Brahmaputra in India, commercial catches are dominated by *Labeo gonius, Wallago attu, Labeo bata* and *Notopterus notopterus,* and major carps are generally less abundant. For subsistence fishers, small indigenous species such as (*C. morar*, *A. coila* and *Neotropius atherinoides*) are numerically dominant and make up over 40 percent of the total catch (Ahmed *et al.,* 2013).

Fishing methods

Different types of fishing nets are used along the Brahmaputra depending on the availability of the type of species and their size. Professional fishers tend to use small boats with more efficient gear (dragnets and seine nets), which generally require greater skill to use. Seasonal fishers use gear that targets small fish (cast nets, push nets, stick hooks and traps) and subsistence fishers use inexpensive simple gear (Ahmed *et al.,* 2013). Fishing intensity is significantly higher in winter and pre-monsoon months than the monsoon months (Boruah and Biswas, 2002). Illegal fishing methods consist of pesticides and explosives in channels and tributaries, monofilament nylon nets and mosquito nets which catch all fish and even eggs (Boruah and Biswas, 2002).

Fish trade

Fishers tend to sell their catches to domestic markets and to local consumers. Much of the fish marketed is fresh, the average price estimated at USD 1.17/ kg with prices depending on species, quality and supply and demand. Average daily income from fishing ranged from USD 1.40 for professional fishers, USD 1.19 for seasonal fishers to USD 1.11 for subsistence fishers (Ahmed *et al.,* 2013).

Employment

There are few estimates in this context. As the Brahmaputra River has the only basin in Bhutan, employment in fisheries is based on fisheries of the river, which in 2013 comprised 92 fishers (FAO, 2017). In Tibet, People's Republic of China, the Brahmaputra River (Tsangpo River) fisheries make up 90 percent of the fisheries; in 2014 there were 86 full-time and 55 part-time fishers (China Agriculture Yearbook, 2014). In Bangladesh, it is estimated that there are 13 million part-time fishers, but there are social restrictions as to who should participate in the fishery. Similarly, in India, only subgroups of Category 4 caste can traditionally fish (Payne and Temple, 1995).

Estimated fisheries production

Due to the lack of fisheries data and reporting systems, estimated fisheries production from India was established using the proportional area of each river basin in each state and separating known aquaculture species from capture species; the resultant catch estimate is presented in Table 26-3.

In Bangladesh, the floodplain fishery accounts for around 63 percent of the total inland production – more than river production. Craig *et al.* (2004) found that catches from riverine habitats declined significantly by about 3 600 tonnes per year from 1983 to 1997, although subsequent data did show some recovery. The floodplain fishery production in Bangladesh in 2015/2016 was 747 872 tonnes, considerably higher than the fishery production from rivers and estuaries within the country (174 458 tonnes). Also, fishery production from *beels* was 95 453 tonnes in the same year (FRSS, 2017).

There is scant information on the state and scale of inland fisheries in Bhutan. But the Brahmaputra flows through the whole country (FAO, 2016) and the total catch in 2015 was 7 tonnes (FAO, 2017). Similarly, in Tibet, People's Republic of China 90 percent of the fisheries are located on the Yarlung Zanbo (as the Brahmaputra is known) which is the main fish producer (Petr, 1999).

Table 26-3. Production estimates for the Brahmaputra River

Country	Area/province	Catch estimate (tonnes)	Year	Reference
India	Assam	110 551	2014	Government of India (2014)
	Meghalaya	2 385		
	Tipura	12 605		
	Mizoram	451		
	Manipur	5 881		
	Nagaland	1 819		
	Arunchal Pradesh	1 834		
Bangladesh	River fishery	2 280	1989–1990	Neiland and Béné (2008)
	Floodplain fishery	843 325	2015–2016	FRSS (2017)
Bhutan		7	2015	FAO (2017)
China (Tibet, PRC)		259	2013	China Agriculture Yearbook, (2014)
Total		**981 397**		

Status of the fisheries: catch trends

In India, there was no information on fish production and the abundance of commercial fisheries in the Brahmaputra River system until 1972 when the Brahmaputra Survey Unit was established by ICAR–CIFRI (the Indian Council of Agricultural Research, Central Inland Fisheries Research Institute). In India, out of 42 fish landing centres located in Assam, only four (Tezpur, Guwahati, Uzan Bazar and Fancy Bazar) were selected for recording fish statistics until 1998, after which CIFRI continued to record fish landings at Uzan Bazar until 2007.

Fish catch composition of the river has changed, and over the years there has been a drastic decline in fish catch from the Brahmaputra River which has severely impacted the livelihoods of landless fishers. Fish stocks in Tibet, People's Republic of China have declined from historical estimates of 500 tonnes (Petr, 1999), even though Tibetan people usually do not eat fish for religious reasons. This was due to an increase in fishing by Tibetan fishers working for Chinese entrepreneurs (Altner, 2010). Catches of major carp, minor carp, catfish, hilsa and other commercial species have declined at all centres, and small miscellaneous species now dominate fish catches. The qualitative shift in fisheries over the years has severely affected the pattern of harvesting from the river (Bhattacharjya, Bhaumik and Sharma, 2017). Overall, there has been a 30 percent decline in the catch of major carp. The average recorded catch at Tezour from 1973 to 1979 was 196 kg/day (19.4 percent being major carp) but this declined to 137 kg/day (11 percent being major carp) (Bhattacharjya, Bhaumik and Sharma, 2017). Fishing activities have led to large-scale destruction of brood fishes and juveniles which has impacted the natural fisheries (Ahmed *et al.,* 2013).

Aquaculture

There is little information regarding the production values of aquaculture within the Brahmaputra River. But in India and Bangladesh there is an established practice of extracting major carp juveniles and eggs from the Brahmaputra River during the monsoon season to support freshwater aquaculture (Rahman, 2008).

26.3 THREATS TO THE FISHERIES

Overfishing

Exploitation of fisheries within the Brahmaputra River is high and threatens the livelihoods of fishers who are vulnerable to declining catch rates. Overexploitation of fish populations and indiscriminate killing of juvenile fish is attributable to unregulated fishing in the system and the lack of alternative livelihood options for fishers (Hussain, 2010). Also, the increase in the dominance of small miscellaneous species and decline in abundance of major carp species is also indicative of overfishing (Bhattacharjya, Bhaumik and Sharma, 2017). Illegal fishing methods are rife within the Brahmaputra Basin and killing of fish using pesticides and explosives is not uncommon. Also, the use of mosquito nets is prevalent in the upper stretches of the river, depleting not only the fish stock but the riverine biota as well (Boruah and Biswas, 2002).

Climate change

Climate models show a gradual increase in temperature in the Brahmaputra River Basin. Average monthly temperature is predicted to increase by 1.3 °C to 2.4 °C by 2050 and 2.4 °C to 5.0 °C by 2100, with the highest temperature increase occurring outside the monsoon season. Evapotranspiration is expected to increase 5 percent to 18 percent by 2050, and average change in rainfall ranges from +15 percent and -14 percent by 2050. The average flow of the river is expected to increase 5 percent to 20 percent with lower flows in the summer and a significant increase in monsoonal flows, driven by increases in glacial melt and runoff (Mahanta *et al.,* 2014). Owing to the impact of climate change on fisheries, it is difficult to predict the greatest net effect on fisheries – reduced dry season flow (lower fish survival and reproduction) or increased monsoonal flows (providing more nutrients and increased feeding for young fish) (WorldFish, 2007).

Water quality

Water pollution is rife in India and is a cause for great concern. Recent industrial growth and urbanization have led to a drastic increase in industrial and municipal waste within the Brahmaputra Basin, particularly around urban centres such as Guwahati. The Bharalu, a major tributary of the Brahmaputra, is severely polluted by industrial and organic pollution from Guwahati and there are no wastewater treatment facilities. A study conducted by Girija, Mahanta and Chandramouli (2007) found that levels of dissolved oxygen and chemical oxygen demand were significantly beyond critical values and eutrophication from untreated sewage disposal was a widespread problem. Also, groundwater contamination by heavy metals such as arsenic, iron and manganese was identified as a serious threat to drinking water and many areas contained contaminant levels higher than WHO drinking water guidelines (Chetia *et al.,* 2010). Although there have been no studies on declining water quality of fisheries in the Brahmaputra Basin, accumulation of contaminants by fish is likely occurring within the basin.

26.4 EQUIVALENT FOOD REPLACEMENT

Fisheries play an important role in nutrition, income and employment particularly in Bangladesh and India, where religious beliefs restrict the availability of other sources of animal protein (Payne and Temple, 1995). In Bangladesh, fish account for 56.2 percent of animal proteins consumed and consumption rates are 16.26 kg/capita/year (FAO, 2011; FAO, 2017).

Given the importance of fish within the basin, the loss of capture fisheries would severely harm populations that depend on fisheries. Also, given the pollution problems and overfishing of the river, equivalent food replacement for a 50 percent loss to the fisheries was based on fishery production (Table 26-3). Replacement food consists of aquaculture (common carp and tilapia), livestock (beef, pork and chicken) and rice.

The Chinese catch from the Brahmaputra was excluded from replacement estimates as catch values were insignificant and unlikely to impact fisheries overall in China; additionally as stated fish catches are not consumed in Tibet, People's Republic of China for religious reasons but marketed in China instead, this catch was not deemed essential for maintaining food security within Tibet, People's Republic of China.

Table 26-4. Food production (tonnes), water (km³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Common carp	296 517 (325.5)	0.93 (0.1)	49 419 (9.1)	
Tilapia	290 307 (102.2)	0.87 (0.1)	13 196 (2.4)	0.08
Beef	304 663 (26.4)	4.70 (0.7)	35 153 (31.2)	19.1
Pork	159 335 (45.4)	0.95 (0.1)	21 728 (19.3)	0.09
Chicken	501 798 (17.3)	2.17 (0.3)	13 465 (12.0)	1.19
Rice	426 528 (0.2)	0.95 (0.1)	935 (0.1)	0.05

Energy replacement (Table 26-4)

Chicken production would require the largest increase in production to replace kilojoules from fisheries, which in terms of current poultry production is equivalent to 17.3 percent (chicken production in 2014 was 2.91 million tonnes for the basin countries). Rice production would require the second largest increase in production but compared to current production this is a small value (0.2 percent) (rice production in 2014 was 210 million tonnes). Pork production would require the smallest increase in production, equivalent to 45.4 percent of current production (pork production in 2014 was 350 932 tonnes).

Water demand (Table 26-4)

Replacement of fisheries with beef production would have the largest impact on water resources, equivalent to 0.7 percent of agricultural water use from India, Bangladesh and Bhutan (agricultural water usage was 719.2 in 2016). Farmed carp, tilapia, pork and rice production would require similar amounts of water to replace fisheries, equivalent to >0.1 percent of current water withdrawals.

Land requirements (Table 26-4)

Common carp production would require the largest land conversion, equivalent to 9.1 percent of the Brahmaputra River Basin area. However, with improvement of water quality within the basin there is room to substantially expand aquaculture practices. Beef production would require 30 153 km² of land to replace fisheries, equivalent to 31.2 percent of the pastureland area within the riparian countries (pastureland area was 112 530 km² in 2018). Rice replacement production would require 935 km² of land equivalent to 0.1 percent of arable land from the riparian countries (arable land within the basin was 1.64 million km² in 2018).

Greenhouse gas emissions (Table 26-4)

Estimated carbon emissions from 50 percent of capture fisheries on the Brahmaputra River were 1.6 million tonnes. Net increase in emissions from replacement food sources was highest for beef production with a net increase of 19.1 million tonnes. Followed by chicken (1.2 million tonnes), pork (0.09 million tonnes), farmed tilapia (0.08 million tonnes) and rice replacement (0.05 million tonnes).

26.5 FISHERIES MANAGEMENT

Despite the importance of the Brahmaputra River there is currently no existing comprehensive agreement concerning water management of the river, either on a sub-basin or basin level. In 2013, The People's Republic of China and India signed a Memorandum of Understanding to strengthen cooperation on transborder rivers, which is an agreement on China's commitment to providing hydrological information.

The absence of robust and trustworthy information on fish catches inhibits efficient management, thus reducing the sustainability of fishers' livelihoods. A Rapid Appraisal of Fisheries Management Systems was established to identify appropriate management strategies for sustainable fisheries management. This involved 25 knowledgeable community members and key informants were contacted to provide information on sustainable management strategies (Ahmed *et al.,* 2013). To implement sustainable fisheries management, the prevailing social, economic and ecological aspects must be considered. Therefore, management within the Brahmaputra River must aim to control overexploitation of the resource, protect the river ecosystem and conserve fishery biodiversity (Ahmed *et al.,* 2013)

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27 GANGES RIVER

27.1 OVERVIEW

The Ganges River (Table 27-1), which has high cultural and religious values, is the fifth largest river basin in the world (Welcomme, 1985). The main river channel originates from the Gangotri Glacier in Nepal and flows for 2 550 km until it discharges into the Bay of Bengal. The Ganges River has two major confluences with the Brahmaputra River on the Bangladesh border, where it flows for another 100 km to its confluence with the Meghna River at Chandpur (FAO, 1999). Altitude within the basin ranges from 8 848 m above sea level in the Himalayas to sea level in the coastal deltas of India and Bangladesh (Payne *et al.,* 2004). The mean annual water discharge is the fifth largest in the world, with a mean flow of 18 700 m^3/s (Welcomme, 1985). The main sources of water in the basin are direct seasonal rainfall and snowmelt. The Ganges River Basin is geographically and environmentally diverse, which is reflected in its resources. Consequently, there is considerable demand and competition for resources, particularly the water itself (Payne *et al.,* 2004).

Table 27-1. Characteristics of the Ganges River

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
India	974 793	79	603 216 193	618
Nepal	147 399	14	28 469 311	193
Bangladesh	46 300	4	148 425 273	1 229
People's Republic of China	33 500	3	33 943	20
Total basin area	**1 201 992**	**100**	**780 144 722**	**515**

Source: JRCB (2011).

Fish diversity

The Ganges River has the highest species richness of any river in India. According to Abell (2008), there are 234 species in the Ganges Delta and 160 species in the upper catchment in the Himalayan foothills, of which 22 are endemic. This contrasts with FishBase, which states that there are 101 species in the Ganges River (FishBase, 2017). However, 29 freshwater fish species have been listed as threatened under vulnerable or endangered categories (Lakra *et al.,* 2010).

Fish introductions

According to Sarkar *et al.* (2012), ten exotic species were recorded from the Ganges River. Abundance was highest for *Cyprinus carpio, Oreochromus mosambicus, Clarias gariepinus*, but *Oncorhynchus mykiss* and *O. niloticus* have also been recorded in the basin (Sarkar *et al.,* 2012).

27.2 FISHERIES OVERVIEW

Cold water upland fisheries depend on the Himalayan sector of the basin. The mountain fisheries are poorly documented, due to the steep gorges of the region making fishing a difficult and dangerous activity. Snow trout constitutes most of the catch (20 percent to 80 percent) with mahseers contributing 20 percent to 27 percent (Bhatt and Pathak, 1992). Owing to the sanctity of certain points along the river, that are central to the Hindu faith, fishing is forbidden in these sites (Payne *et al.,* 2004). In the warmer waters of the lowland basin, fishers are characterized as 'professional', 'part-time' or otherwise, with professional fishers falling into well-defined social categories who render their fishing villages identifiable. In the middle and lower reaches, major carp (catla, mrigal, rui and calbasu) constitute as much as 53 percent of the total catch in some districts. The pattern of fishing coincides with premonsoon and postmonsoon seasons, which coincide with the migratory movements of target species (Payne *et al.,* 2004).

Fishing methods

The variety of habitats in the Upper Ganges and the difficulty of the environment have led to various fishing techniques (Shrestha, Seidl and Moraes, 2002). The most common type of fishing gear is cast nets that are used along the tight meanders. Also, a local technique known as 'fase' or 'passo' which is a longline technique that uses a series of nylon loops to catch snow trout. The use of dynamite, electricity and traps is also common (Payne *et al.,* 2004). The main gear types used in the lowland areas are seines or dragnets, gillnets, scoop nets, cast nets, longlines and traps.

Fish trade

Much of the main channel from the floodplains up to its source is a pilgrimage route along which the consumption of fish or meat is not encouraged. Markets in these areas are therefore limited. Additionally, as in the upland areas, religious influences on dietary habits along the river imply that local markets are unevenly distributed throughout the basin. The major fish marketing areas are West Bengal and Calcutta, where there is a long tradition of eating fish and where the demand is highest (Payne *et al.,* 2004).

Employment

There are few indications as to participation in fishing activities in India, but in Bangladesh, it is estimated that at least 13 million people are part-time fishers. There are also social restrictions as to who should participate in the fishery. In India only subgroups of Category 4 caste can traditionally fish, and this still largely holds. The situation is similar in Nepal, although divisions are less distinct. In Bangladesh, the Muslim majority traditionally does not fish and leaves this sector to the minority Hindu population. However, as population pressure increases, this is changing and as people become increasingly landless, more people are being forced into fishing as a last resort (Payne and Temple, 1996).

Estimated fisheries production

Estimated fish production from the Ganges River is outlined in Table 27-2. Information on fishery catches in the Ganges is fragmented and reflects the scant work done on a national or basin-wide survey. In addition, most fishery surveys so far have been based on selected landing sites (Jhingran, 1991). As such, estimated fisheries production was established by separating the known aquaculture species and capture fishery species and then allocating the capture fishery estimate using the proportional area of each Indian state within the Ganges River Basin. Although there is a 25 percent discrepancy with this approach, it is the best available as there is a dearth of local fish data.

Table 27-2. Production estimates for the Ganges River

State	Catch estimate (tonnes)	Year	Reference
Himachal Pradesh	178	2014	Government of India (2014)
Haryana	19 660		
Rajasthan	3 594		
Madhya Pradesh	10 695		
Chhattisgarh	10 943		
Jharkhand	8 025		
Bihar	164 200		
Uttar Pradesh	87 747		
West Bengal	123 351		
Sikkim	260		
Delhi	135		
Uttaranchal	751		
Total	**429 540**		

A more comprehensive update of the capture fishery data of the Indian states and the respective river basins is sorely needed to understand the relative contributions of inland capture-fisheries in the Indian sub-continent.

Status of the fisheries: catch trends

Fish catches in the Ganges River have generally declined since initial surveys conducted in 1957 by ICAR–CIFRI. Average fish landings in the Upper Ganges (between Kanpur and Allahabad) declined from 119.35 tonnes in 1959 to 78.15 tonnes in 2004. Similarly, average fish landings in the middle stretch declined from 69.53 tonnes to 20.58 tonnes in 2004 (ICAR–CIFRI, 1959–2004). In the lower basin there has been an increase in fish catch due to the rapid expansion in population (the delta in Bangladesh has the highest population density in the world).

Aquaculture

There is little information regarding production estimates for aquaculture within the Ganges River Basin. Given the richness of natural fish fauna in the Ganges River, a large variety of fish is transferred to ponds for harvest. There is also an established practice of collecting major carp juveniles from rivers to supply seed to the carp aquaculture industry, however this aspect of the fishery is not well developed. In Bangladesh major carp spawn are collected from the Ganges in the Padma region, although the numbers and values are unknown (Rahman, 2008).

27.3 THREATS TO THE FISHERIES

Climate change

Climate change projections for the Ganges Basin indicate an average basin temperature increase of 4.1 °C by the end of the century, with increases of 19.8 percent and 13.6 percent for precipitation and evapotranspiration, respectively, due to temperature rises (Masood *et al.,* 2015). Temperature increases will also affect the hydrology of the river, with less precipitation falling as snow and an increase in snowmelt. Summer snowmelt provides low flows during the dry season, and perturbation of this process will affect the seasonal runoff causing an initial increase in dry season flows, but in the long term as the summer snowmelt diminishes, dry season flows could be reduced by as much as 10 percent to 24 percent (Jeuland *et al.,* 2013). An increase in rainfall in the post-monsoon months of September to December would also severely impact major carp recruitment and reduce the fish productivity of the river (Vass *et al.,* 2009).

Habitat modification

In India, barrages control all the tributaries to the Ganges and divert roughly 60 percent of the river flow to large-scale irrigation (Abell *et al.,* 2008). There are 30 upstream water diversions in India; the largest include the Farakka Barrage, Tehri Dam and the Hardwar Dam (Payne *et al.,* 2004). All of these structures modify the flow of the river and influence fish distribution. The Farakka Barrage, the largest dam along the Ganges, has had a significant impact on fisheries with decline of the anadromous hilsa (*Tenualosa ilisha*) in the Bangladeshi fishery (Payne *et al.,* 2004); catches of the species diminished from 24 percent in 1985 to 11 percent in 2010/2011 (DoF, 2012). This decline occurred despite warnings of the damaging potential of dams for this species (Hickling, 1961). Similarly, the Tehri Dam has considerably attenuated water flow, destroyed the feeding, spawning and migration routes of masheer (Sharma, 2003), and has disrupted the migratory routes of yellow catfish, Pangasius catfish and long-whiskered catfish (Sarkar *et al.,* 2012).

Water quality

More than 29 cities, 70 towns and thousands of villages line the banks of the Ganges River. They discharge around 1.3 billion litres of sewage per day into the river. Another 260 million litres of industrial waste are added by factories along the river and 2 573 tonnes of pesticides are applied annually for pest control

(Sinha, 2007). According to research, some fish have significant accumulations of chemicals such as dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane (HCH) that are higher than the permissible limits set by the United States Environmental Protection Agency (Samanta, 2007). In some areas the water quality is so poor that fish populations, especially the valuable major carp species, have declined greatly (Natarajan, 1989), and fish die-offs are reported from time to time (Das, Samanta and Sah, 2007). Clearly, consumption of these fish poses a threat to human health. Heavy metal contamination also occurs in the middle and lower reaches of the river where industrial discharges have contaminated river sediment with heavy metals such as chromium, cadmium, zinc and copper (Vass *et al.,* 2010).

27.4 EQUIVALENT FOOD REPLACEMENT

For people who participate in fisheries, fish are important dietary elements in India and especially in Bangladesh, where religious beliefs otherwise restrict the availability of animal protein (Payne and Temple, 1996).

Given the cultural and religious importance of fish within the basin, the loss of capture fisheries would be detrimental to these sections of society and in some communities, replacement of fish with other animal protein sources would contravene religious beliefs. For these reasons and owing to the increasing pollution problems within the basin, replacement estimates were established for a 50 percent loss of the total basin capture fisheries from Table 27-2. Replacement food sources are livestock (beef, pork and chicken), aquaculture (common carp and tilapia) and rice.

Table 27-3. Food production (tonnes), water (million m^3), land (km^2) and net increase in carbon emissions (thousand tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m^3 (percentage of agricultural water use)	Land required to replace fisheries in km^2 (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (thousand tonnes)
Common carp	1 231 (1.3)	3.84 (0.0005)	205 (0.02)	No data
Tilapia	1 205 (0.4)	3.60 (0.0005)	55 (0.005)	0.3
Beef	1 265 (0.1)	19.50 (0.003)	145 (0.1)	7.92
Pork	661 (0.2)	3.96 (0.0005)	90 (0.07)	0.4
Chicken	2 083 (0.07)	9.01 (0.001)	56 (0.04)	0.49
Rice	1 771 (0.0008)	3.94 (0.0005)	4 (0.0002)	0.2

Energy replacement (Table 27-3)

Chicken as a replacement source would require the largest increase in production, equivalent to 0.07 percent of current chicken production in India, Nepal and Bangladesh (2014 production was 2.94 million tonnes). Pork production would require the smallest increase in production, equivalent to 0.2 percent of current production (2014 production was 369 268 tonnes). Rice would require 1 771 tonnes to replace kilojoules from capture fisheries, however, all the Ganges Basin countries are major producers of rice and replacement values are only equivalent to 0.0008 percent of current rice production (2014 rice production was 214 million tonnes).

Water demand (Table 27-3)

The Ganges River Basin countries are significant users of freshwater, mostly for agriculture and irrigation. Therefore, in terms of current water withdrawals, the proportion of water needed to replace fisheries with other food sources is small. Beef replacement would have the largest impact on water resources, equivalent to 0.003 percent of current water withdrawals from India, Bangladesh and Nepal (agricultural water use in the riparian countries was 728 km^3 in 2016).

Land requirements (Table 27-3)

Farmed common carp production would require the largest land area to replace fisheries, equivalent to 0.02 percent of the area of the Ganges River Basin. Beef would require the second largest land use, equivalent to 0.1 percent of the pastureland in India, Bangladesh and Nepal (2014 pastureland area was 126 353 km^2). Rice production would require the smallest expansion of 4 km^2 to replace fisheries, equivalent to 0.0002 percent of the total arable land from the riparian countries (arable land area in 2014 was 1.66 million km^2).

Greenhouse gas emissions (Table 27-3)

Estimated carbon emissions from 50 percent of the capture fisheries on the Ganges River were 7 661.87 tonnes. Additional emissions from the replacement of capture fisheries indicate that replacement with beef would result in the largest net increase in emissions of 79 209 tonnes, followed by chicken production (4 935 tonnes), pork production (365 tonnes), farmed tilapia (313 tonnes) and rice (203 tonnes).

27.5 FISHERIES MANAGEMENT

The socio-economic religious pressure exhibited at certain points along the river influences access to and participation in the fisheries. The free, open-access approach to all natural-resources used by other religions is not practised in the Ganges River Basin (Payne and Temple, 1996).

National management strategies

Each of the riparian countries has developed its own managerial policies, but there is no basin management body. In India, the Ganga River Basin Management Plan is currently in preparation to rehabilitate the Ganga ecosystem. The two main objectives are:

- To ensure effective mitigation of pollution and rejuvenation of the Ganges by adopting a river basin approach to promote intersectoral coordination for comprehensive planning and management.
- To maintain minimum ecological flows in the Ganges to ensure water quality and environmentally sustainable development (National Mission for a Clean Ganga, 2017).

In India, there are more than 690 wildlife protection areas, four of which are within the Ganges River Basin, which contribute towards conservation. Many fish use these protected areas as breeding and spawning grounds. Fishing in these areas is totally prohibited and as a result fish diversity is high (Sarkar *et al.,* 2012). Baird (2006) reported that fish conservation zones can benefit fish stocks, especially sedentary species, but also highly migratory species, and concluded that fish sanctuaries are important tools in participatory community-based fisheries and co-management programmes.

Transboundary management

The Indian Government established the Joint Rivers Commission (JRC) with Bangladesh in 1972 as a major bilateral top-down water management institution for the Ganges River but it does not include the other basin countries of the People's Republic of China and Nepal (Arango *et al.,* 2010). The aim of the JRC was to facilitate dialogue between the countries to ensure the most effective joint efforts to maximize benefits from common river systems in both countries. However, the JRC is dominated by cooperate elites that view water as a commodity and fail to recognize the importance of the Ganges biological ecosystems and their historical significance (Hossan, 2015); as such fisheries are totally excluded.

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28 INDUS RIVER

28.1 OVERVIEW

The Indus River (Table 28-1) is the twelfth largest river in the world (FAO, 2016) and covers a length of 3 200 km. It originates in Tibet, People's Republic of China in the Himalayas at an elevation of 5 500 m. From its source, the river flows from Tibet, People's Republic of China into India and then through Pakistan and south through the highland province of Khyber Pakhtunkhwa. After emerging from this highland region, the river descends 260 feet onto a large floodplain and continues until it empties into the Arabian Sea (FAO, 2016). In Pakistan, the Indus River covers 65 percent of the territory, comprising all of the provinces of Punjab, Khyber Pakhtunkhwa and most of Sindh Province (FAO, 2016). The river has 27 major tributaries, the largest of which is the Shyoke River (NDMA-UNDP, 2010). Other major tributaries are the Kabul River and the Panjnad River. The average annual flow of the Indus River is 207 m^3 x 10^9 m^3 and is twice that of the Nile and three times that of the Tigris–Euphrates rivers. The flow of the Indus River depends on season; it decreases during the winter, but monsoon rains and snowmelt in the summer cause the river to rise and widespread flooding is common (FAO, 2016).

Table 28-1. Characteristics of the Indus River

Country	Area of the river (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
Pakistan	520 000	47	148 222 755	341
India	440 000	39	43 262 713	140
People's Republic of China	88 000	8	53 110	1
Afghanistan	72 000	6	12 079 893	169
Total	**1 120 000**	**100**	**203 618 482**	**163**

Fish diversity

According to FishBase there are 81 fish species in the Indus River, the most abundant families being Cyprinidae (31 species) and Sisoridae (14 species) (FishBase, 2017). This differs from the World Wildlife Fund (WWF) estimate, which states that there are 147 fish species, of which 22 are endemic (Wong *et al.,* 2007). The river is also the habitat for the endangered Indus river dolphin (Smith and Braulik, 2012).

28.2 FISHERIES OVERVIEW

Fishing in the Indus River primarily constitutes small-scale artisanal fishing communities on its tributaries, freshwater lakes, man-made reservoirs and floodplains (Khan, 2016). The Indus River contains the world's largest network of irrigation channels and earth-filled dams, barrages, freshwater lakes and floodplains. Fish catches from the Indus River and reservoirs make up 80 percent of Pakistan's total inland production (Akhtar, 2010). Little is known about the fishery resources of the Indus River, but fishery composition likely consists of Indian major carp, tilapia, catfish, *Labeo* spp., wallago and khagga (*Rita rita*) (Department of Fisheries Punjab, 2017).

Fishing methods

Historically, traditional fishing methods such as manual fishing gear operated from small wooden boats were the norm along the Indus River, and were considered environmentally friendly. New technologies led to the use of modern gear. In Punjab, there are nine different types of cast nets, which are used mainly to catch small fish. There are three types of drag and seine nets for catching hilsa that need 10 to 15 people to deploy. There are two types of gillnets, known as *nara* and *jhani*. Various types of hand nets, rods and lines, fixed nets and drift nets are also used (Department of Fisheries Punjab, 2017). The introduction of new technologies with better nylon nets and finer mesh sizes has been attributed as the cause for the increasing unsustainability of fish stocks (Khan, 2016).

Fish trade

Fisheries of the Indus River play an important role in the national economy, particularly in Pakistan where the fishing industry is worth USD 1.2 x 10^9 (Akhtar, 2010). Fisheries also contribute 1 percent to Pakistan's GDP and 3 percent to the agricultural GDP (FAO, 2009). Fish are traded throughout the Indus region, and in Punjab, retail markets are established in almost all cities and towns in the province. The perishable nature of fish, lack of market infrastructure and transport facilities, and limited taste for fish are factors which have complicated the related marketing system (FAO, 2009).

Employment

The involvement and participation in fisheries in the Indus River Basin are not known. In Pakistan, fisheries provide food and income for over 400 000 people and almost 1 million people are indirectly dependent on freshwater fisheries resources (Khan, 2016).

Estimated fisheries production

Table 28-2 indicates the estimated fisheries production from the Indus River by country. The only countries for which data were available were People's Republic of China, Pakistan and India. There was no breakdown of values by water basin or area in Pakistan, but as the Indus River fishery constitutes about 80 percent of the catch in Pakistan, this proportion was calculated for the total inland fishery catch in Pakistan in 2014 (265 000 tonnes). Fisheries in Pakistan are characterized by limited information about fish stocks and little or no stock assessment is carried out (Khan, 2016). As such, the figures for fisheries catches in Pakistan in Table 28-2 are not likely to be an accurate representation of actual fisheries catches. In addition, in People's Republic of China, fisheries catches are reported by province; therefore the figures in Table 28-2 may not be representative of the fisheries production of the headwaters of the Indus, as the headwaters of the Yangtze, Brahmaputra and Mekong rivers are also sourced in the Himalayas (Tibet, People's Republic of China). Finally, fishery estimates from India were also established using the proportional area of each Indian state within the basin, with a discrepancy of counting only species known in capture fisheries, which introduces some error.

Table 28-2. Estimated fisheries production for the Indus River

Country/state		Catch estimate (tonnes)	Year	Reference
People's Republic of China (Xinjiang Uygur)		37	2015	China Agriculture Yearbook (2014)
Pakistan		212 000	2014	Pakistan Statistical Yearbook (2014)
India	Punjab	19 461	2014	Government of India (2014)
	Himachal Pradesh	1 518		
	Jammu and Kashmir	9 764		
	Rajasthan	21		
Total		**242 801**		

Status of the fisheries: catch trends

Despite catch trends from the Pakistan Department of Fisheries indicating an increasing trend in fish catches (from 136 000 tonnes in 2005 to 212 000 tonnes in 2014), there is conflicting literature that supports the view that fisheries from the Indus River are declining. However, there are no figures that would indicate the extent to which fisheries have declined, as no comprehensive fisheries assessment has been carried out. The decline in the Indus River fisheries is attributed to multiple factors: overfishing; reduced river flow due to climate change and drought over the last 50 years; degradation of water quality and riverine environment; agricultural runoff; urbanization and population explosion (Khan, 2015; Khan, 2016). In addition, illegal unsustainable fishing, non-enforcement of fishing regulations and poor marketing infrastructure are also considered to be factors in this context.

Aquaculture

Fish farming has been used to compensate for the decline in capture fisheries and address the growing threat to food security of poor inland fishing communities. Semi-intensive integrated carp (Chinese and Indian major carp) and Nile tilapia pond aquaculture have shown huge potential in the agricultural heartlands of Punjab and Sindh provinces (Khan, 2016). In Tibet, People's Republic of China aquaculture production in 2012 produced 65 tonnes of fish and fishery products (China Agriculture Yearbook, 2014).

Recreational fisheries

Trout angling is hugely popular in the Jammu and Kashmir regions of India. The angling season is open between April and September, but the duration of angling can be extended or shortened by the Directorate of Fisheries. A licence is required for angling, which is only valid for one day, with a limit of six fish. Only artificial fly fishing is allowed with rod and line being the only acceptable gear – only one rod/person (Department of Fisheries Government of Jammu and Kashmir, 2017).

28.3 THREATS TO THE FISHERIES

Overfishing

No figures are available that would indicate that fisheries in the Indus River are overfished, primarily due to the lack of any formal stock assessment. Many fishers from the river have found that their catches have declined significantly over the past 20 years. Increasing human pressure from a growing population has meant that over the past 20 years the fishing fleet has grown by 15 percent, which corresponds with a decline in fishery resources and fish catches. The lack of other livelihood options has meant that poverty-driven overfishing by artisanal fishers creates a vicious poverty–resource degradation nexus (Khan and Khan, 2011). Also, due to a shortage of funding for management and trained human resources, fisheries departments and other enforcement agencies are ill-equipped and unable to implement and enforce fishing regulations, thereby promoting overharvesting and decline of freshwater fisheries in Pakistan (Khan, 2016).

Climate change

Climate change predictions suggest a minimum temperature increase over the whole basin of up to 2.4 °C to 4 °C by 2050 and 4.3 °C to 5.1 °C by 2080. Precipitation levels indicate a slight decrease in rainfall intensity towards the northwest part of the basin by 2020 and then progressive increases towards 2080 (Rajbhandari *et al.,* 2015). The Indus River is sensitive to climate change due to the high portion of the river flow that is derived from glaciers and glacial melt. The Himalayan glaciers provide the Indus with 70 percent to 80 percent of its water (Kiani, 2005), the highest portion of any river in Asia. The Indus River is already suffering from severe water scarcity due to overextraction of water for agriculture and irrigation, and from increasing water demand from an increasing population. Increasing prevalence of droughts (1968–1969, 1971–1974, 1985–1987 and 1999–2002) has further added to the increasing problem of water scarcity that threatens fisheries (Rasul *et al.,* 2012).

Water quality

Increasing industrialization and population of the basin has led to a large increase in pollution discharges into the river. Studies by Jabeen and Chaudhry (2010) and Jabeen and Chaudhry (2009) found that heavy metal contamination of common carp and tilapia from different areas of the Indus River was above the levels set out in water quality guidelines and standards by international organizations (UNEPGEMS, 2006). Levels of manganese, mercury and chromium accumulation in these fish species were high and would damage the health of human consumers in these study areas (Jabeen and Chaudhry, 2010).

28.4 EQUIVALENT FOOD REPLACEMENT

Fisheries information for the Indus River regarding catch trends, historical data and the current state of the fishery is severely lacking. It is indisputable that fisheries are a vital source of income and livelihoods for rural communities, and the lack of alternative income and the increasing population have forced people into fishing to sustain their livelihoods. Equivalent replacement estimates were established for a 50 percent reduction in estimated fisheries production (Table 28-2). Replacement foods consist of aquaculture (common carp and tilapia), livestock, (beef, pork and chicken) and crops (rice). Replacement estimate discussion will only be based on Pakistan and India as they form the largest portion of the basin.

Table 28-3. Food production (tonnes), water (km³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area.

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Common carp	73 360 (390.2)	0.23 (0.03)	12 227 (1.3)	
Tilapia	71 824 (30563.2)	0.21 (0.03)	3 265 (0.4)	0.02
Beef	75 375 (4.2)	1.17 (0.2)	8 697 (2.5)	4.71
Pork	39 420 (11.3)	0.24 (0.03)	5 376 (1.5)	0.03
Chicken	124 148 (3.3)	0.54 (0.08)	3 331 (0.9)	0.29
Rice	105 525 (0.1)	0.24 (0.03)	231 (0.01)	0.01

Energy replacement (Table 28-3)

Aquaculture practices are limited in India and Pakistan. To replace kilojoules from capture fisheries with farmed tilapia would require a 30 563.2 percent increase in current production (2015 production was 235 tonnes, only from Pakistan). Common carp production would have to increase by the equivalent to 390 percent of current production (2015 production was 18 800 tonnes, only from India). Rice production would require 105 525 tonnes to replace kilojoules from capture fisheries, but rice production in the riparian countries is high and this value only represents 0.1 percent of current production (2014 production was 164 million tonnes).

Water demand (Table 28-3)

Water use would have to increase significantly within the drought-prone Indus Basin to replace capture fisheries. Beef would require the largest water demand, equivalent to 0.2 percent of agricultural water use in India and Pakistan (agricultural water use was 116.7 km³ in 2016). Aquaculture production would require the smallest water demands for common carp and tilapia respectively, equivalent to 0.03 percent of agricultural water use from India and Pakistan. These figures are likely underestimated, as future climate projections indicate that a 5 °C rise in temperature is expected increase domestic animal and crop water requirements by 1.5 times compared to current levels (Rasul *et al.,* 2012).

Land requirements (Table 28-3)

Farmed common carp would require the largest land conversion, equivalent to 1.3 percent of the Indus River Basin area in Pakistan and India (96 000 km²). Beef production would require 8 697 km² of land to replace capture fisheries, equivalent to 2.5 percent of pastureland in India and Pakistan (the 2014 pastureland area was 354 400 km²). Chicken production would require the smallest land conversion of 3.331 km², equivalent to 0.9 percent of pastureland in India and Pakistan.

Greenhouse gas emissions (Table 28-3)

Estimated carbon emissions from 50 percent of capture fisheries from the Indus River were 399 030 tonnes. Replacement of capture fisheries with other food sources would lead to a net increase in carbon emissions. The highest of which would result from replacement with beef production (4.71 million tonnes), followed by chicken (0.29 million tonnes), pork (21 803 tonnes), farmed tilapia (18 687 tonnes) and rice cropping (12 103 tonnes).

28.5 FISHERIES MANAGEMENT

National management strategies

In Pakistan riverine fishery management is operated by provincial fisheries departments. They enforce regulatory laws that restrict catch by size of fish and establish closed seasons (FAO, 2009). For instance, the Department of Fisheries in Punjab is governed by the Fisheries Ordinance, 1961. District fisheries officers are responsible for the conservation, management and development of district waters and are empowered to lease out fishing rights. Fishing regulations in Punjab comprise issuing of fishing licences and stipulating allowable fishing gear. Size limits and closed seasons are also implemented, for instance trout cannot be caught between 10 October and 9 March and must be over three inches long. Similarly, rahu cannot be caught between June and August and must be over 12 inches long (Department of Fisheries Punjab, 2017). However, Khan (2016) found that fisheries management was characterized by limited information about fish stocks, as little or no information regarding fish stocks has been collected, and fisheries officers rarely enforce fishery regulations.

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29 CASPIAN SEA

29.1 OVERVIEW

The Caspian Sea is the largest lake in the world and whether it should be classified as a large lake or a sea is legally undetermined. The Caspian Sea is approximately 1 200 km long and 310 km wide, its drainage area covers 3 625 000 km (Table 29-1) and has a perimeter of about 6 380 km which is shared among five countries: Azerbaijan, the Islamic Republic of Iran, Kazakhstan, the Russian Federation and Turkmenistan (Bogutskaya, 2015a). The sea contains some 78 200 km^3 of water, about one-third of the world's inland surface waters. The lake is divided into three basins. The northern shallow basin which covers an area of 80 000 km^2; the middle basin that covers an area of some 138 000 km^2 with an average depth of 200 m and maximum depth of 800 m; and the southern basin that covers an area of about 168 000 km^2; it is also the deepest part with a maximum depth of over 1 000 m (Abdolhay, 2004). Over 130 rivers provide inflow into the Caspian Sea, the largest of which is the Volga, which provides about 80 percent of the total flow into the sea (Bogutskaya, 2015b). Other major inflows include the Ural River (Russian Federation, Kazakhstan), the Kura River (Turkey, Georgia and Azerbaijan), the Terek River (Georgia and Russian Federation) and the Shahrood River (Islamic Republic of Iran) (Abdolhay, 2004). The salinity of the Caspian Sea varies and increases from north to south. Maximum salinity occurs in shallow bays and covers the eastern and southeastern coast, reaching 14.15‰ (parts per thousand) while the freshwater inflow from the Volga and Ural rivers in the north means the salinity in the north coast of the basin is approximately 1-5‰, and in the open waters the salinity reaches 12.9‰ (Boguskaya, 2015a).

Table 29-1. Characteristics of the Caspian Sea

Country	Area of the lake (km^2)	Percent area of the lake in countries	Population of the lake basin	Population density/km^2
Kazakhstan	113 000	29.9	1 317 543	3
Turkmenistan	79 000	19.2	4 717 999	11
Azerbaijan	78 000	20.7	9 702 908	93
Russian Federation	64 000	15.6	8 668 129	35
Islamic Republic of Iran	44 000	14.6	23 391 791	73
Total	**378 000**	**100**	**43 080 280**	**51**

Fish diversity

According to Kazancheev (1981) there are 123 species and subspecies of fish in 17 families in the Caspian Sea. This differs with the estimate from FishBase which states that there are 152 species in the Caspian Sea. There are also five endemic species: the Caspian spined loach (*Sabanejewia caspia),* Tabarestan riffle minnow (*Alburnoides tabarestanensis),* Caspian bighead goby (*Ponticola gorlap*), *Benthophilus ragimovi* and *B. ctenolepidus* (FishBase, 2017). The Caspian Sea is also habitat for seven species of sturgeon: the Siberian sturgeon (*Acipenser baerii*), the Russian sturgeon (*A. gueldenstaedtii*), the fringebarbel sturgeon (*A. nudiventris*), the Persian sturgeon (*A. persicus*), the sterlet sturgeon (*A. ruthenus*), the stellate sturgeon (*A. stellatus*) and the beluga sturgeon (*Huso huso*) (Abdolhay, 2004; FishBase, 2017). With the exceptions of the stellate sturgeon (vulnerable) and the Siberian sturgeon (endangered), the other sturgeon species are classed as critically endangered by the IUCN (IUCN, 2017).

Fish introductions

According to FishBase there have been 21 fish introductions to the Caspian Sea. These consist of the Siberian sturgeon (*Acipenser baerii*), European eel (*Anguilla anguilla*), goldfish (*Carassius auratus*), grass carp (*Ctenopharyngodon idella*), bighead carp (*Hypophthalmichthys nobilis*), stone moroko (*Pseudorasbora parva*), European anchovy (*Engraulis encrasicolus*), three-spined stickleback

(*Gasterosteus aculeatus*), striped bass (*Morone saxatilis*), golden grey mullet (*Liza aurata*), leaping mullet (*Liza saliens*), flathead grey mullet (*Mugil cephalus*), red mullet (*Mullus barbatus*), European flounder (*Platichthys flesus*), eastern mosquitofish (*Gambusia holbrooki*), pink salmon (*Oncorhynchus gorbuscha*), chum salmon (*O. keta*), coho salmon (*O. kisutch*) and rainbow trout (*O. mykiss*) (FishBase, 2017).

29.2 FISHERIES OVERVIEW

The main fishery activities on the Caspian Sea are commercial fishing, which differs in each of the littoral countries. Three species of kilka (*Clupeonella cultriventris, C. engrauliformis* and *C. grimmi*) are important commercially in the Caspian Sea, together accounting for more than 80 percent of the total catch as well as being an important part of the food chain. Anchovy kilka are fished all year, mainly in the central (~40 percent of the catch) and southern (~60 percent of the catch) Caspian Sea (Daskalov and Mamedov, 2007). Under a special treaty, the kilkas in the Kazakhstan portion of the basin are caught by the Russian Federation (Mitrofanov and Manilov, 2015).

In the Islamic Republic of Iran, the commercially exploitable fish in the South Caspian Sea are divided into three groups. Firstly, the distant water fishery which mainly consists of herring (*Clupeidae* spp.), which have formed an extensive fishery since the 1980s. The second group, the coastal fishery, focuses on six families Cyprinidae, Mugilidae, Clupeidae, Salmonidae, Percidae and Esocidae that are harvested by beach seine nets. The third group is the sturgeon fishery, which is the most valuable in the basin (Abdolhay, 2004). In Kazakhstan the main fishery targets are sturgeons, cyprinids, pikeperch and kilkas (Mitrofanov and Mamilov, 2015). The Russian Federation commercial fishery on the Caspian Sea targets roach, bream, walleye, carp, freshwater catfish, pike, herring and anchovy sprat which is the largest component of the fishery (Environmental Protection Act, 2017). In Azerbaijan several cyprinid and salmonid species, herring and mullet are the main target species for commercial fisheries in the Caspian Sea (Salmonov *et al.,* 2013). The Caspian Sea has traditionally been known as the sea of sturgeon, as it produces more than 90 percent of the world's caviar (Adbolhay, 2004). The sturgeon fishery is the most lucrative in the basin, with beluga caviar in 2009 being sold for up to USD 8 000/kg (Doukakis *et al.,* 2009).

There have been numerous fishing bans in the Caspian Sea on sturgeon fishing: In 1962 there was a ban in the Caspian Sea, but fishing in the Volga and Ural Rivers was allowed to continue. In 1996, another ban was instigated throughout the Caspian Sea (Khodorevskaya *et al.,* 1997) and in 2002 the Russian Federation banned all fishing for sturgeon in the Caspian Sea, except for catch for restocking and research purposes (Timirkhanov *et al.,* 2010). In 2010, at the end of the Caspian Summit, the littoral states agreed on a five-year ban on sturgeon fishing, which was prolonged for another two years in 2015 (Al-Monitor, 2015).

Fishing methods

In the Islamic Republic of Iran, sturgeon were previously caught using longlines, but this was deemed harmful to immature sturgeon. Only anchored gillnets can now be used to catch sturgeon, although some may be caught accidentally using beach seines. There is a standard mesh size, length and width of gillnets for each sturgeon species (Abdolhay, 2004). Other fishing activities include dhow fishing for kilka and beach seining for bony fish (FAO, 2015). Previously in the 1970s and 1980s, large catches of kilka were made using light-fishing with cone nets and fish pumps (Daskalov and Mamedov, 2007). In Kazakhstan, seine nets and drift nets are used on the Caspian Sea; there is presently no open water fleet and fishing is limited to the near shore (FAO, 2004).

Fish trade

In the Islamic Republic of Iran, the socio-economic valuation of the Caspian Sea is based on the values of the sturgeon fishery, which since 1999 have fluctuated as a result of the sturgeon fishing ban. Previously, in 1989 the sturgeon fishery export value was USD 49 million, which increased to USD 63.5 million in 1990. The export value then decreased to USD 52 million in 1994 and further still to USD 45 million in

1995 (mainly due to reduced caviar production). Since then the value increased to USD 55.5 million in 1999 but fell again to USD 32.7 million in 2003 (FAO, 2015). These values have declined drastically since the ban on sturgeon fishing in 2010, but no figures are available.

In Kazakhstan, the value of the Caspian Sea fishery is not known, but the fishery sector (capture and culture) contributes less than 0.8 percent to the GDP. But the value of illegal and unreported fishing in Kazakhstan is estimated at between USD 1.5 million and USD 2.3 million (Timirkhanov *et al.,* 2010).

In Azerbaijan, sturgeon products are mainly exported to Canada, Germany and the United States, while kilka products are exported to Georgia and the Russian Federation. The value of the Caspian Sea fishery in Azerbaijan is not known, but the sturgeon caviar fishery is the most valuable with sturgeon caviar valued at USD 1 000 to USD 1 200/kg, which far exceeds sturgeon meat valued at USD 30 to USD 50/kg (Salmonov *et al.,* 2013).

Employment

Employment figures for participation in fishing activities in the Caspian Sea were difficult to establish. In Azerbaijan, in 2008 there were an estimated 1 400 fishers on the Caspian Sea. However, this does not include those involved in the secondary sector for which employment figures are difficult to collect (Salmonov *et al.,* 2013).

There are various estimates for participation in fishing activities in Kazakhstan on a country level but there are no estimates for participation in Caspian Sea fishing. Official statistics from the Ministry of Agriculture in 2006 stated that participation in fishing was high, with 17 300 fishers (Timirkhanov, Chaikin and Makhambetova, 2007). But the World Bank estimates that the real number of fishers could be as high as 110 000 (Timirkhanov *et al.,* 2010).

In Islamic Republic of Iran, the number of registered fishers declined from 13 000 in 2007 to 11 284 in 2014, with declining fish stocks being the main cause for the decline in the number of fishers. Also, in an effort to promote sustainable exploitation of fish resources, the Iranian Parliament authorized the reduction of the kilka fishing fleet and bottom trawl fishing fleet and bought-back 245 fishing licences when they expired to prevent further exploitation of fish resources (FAO, 2015).

Estimated fisheries production

Table 29-2 indicates the estimated fisheries production for the Caspian Basin from various literature sources. In Azerbaijan, the 2010 fisheries catch from the Caspian Sea was the lowest for at least ten years, with peak catches in 2005 of 26 400 tonnes and an average catch of 23 657 tonnes between 2000 and 2009. The largest portion of the catch in 2010 was made up of unknown species for which there are no quotas (16 000 tonnes). Species catches for which quotas are required were highest for anchovy sprat (708 tonnes), which is a decline from 18 250 tonnes in 2000 (Salmonov *et al.,* 2013).

Table 29-2. Estimated fisheries production for the Caspian Sea

Country	Catch estimate (tonnes)	Year	Reference
Azerbaijan	17 205	2010	Salmonov *et al.* (2013)
Turkmenistan	8 486	1997	FAO (1998)
Islamic Republic of Iran	39 647	2014	FAO (2015)
Kazakhstan	13 631	2006	Timirkhanov *et al.* (2010)
Russian Federation	33 981	2018	FAO (forthcoming)
Total	**112 950**		

The fishery catches from Turkmenistan in Table 29-2 are an underestimation of current production, but there were no other more recent fishery estimates.

In the Russian Federation, the 2018 fish catch was primarily made up of rudd (6 165 tonnes) (18 percent), for which catches have remained stable over the last four years. Catches of freshwater catfish made up 15 percent of the total fish catch (5 018 tonnes), which represented 57 percent of the total allowable catch (TAC) (8 741 tonnes) (FAO, forthcoming). Catches of northern pike in 2018 amounted to 4 699 tonnes and catches are considered stable with the prospect of a steady increase over the next few years. Catches of roach have been in a steady decline since 2005. The 2018 fishery catch for roach was estimated at 269 tonnes, which was a decrease from 2013 (the lowest for ten years at 1 039 tonnes) and 14 percent of the average for 2004 to 2012. Other species of commercial interest in the Russian Federation are crucian carp (4 315 tonnes) and freshwater bream (4 001 tonnes) (FAO, forthcoming). Catches of sturgeon by private commercial companies and for research purposes have declined significantly in the Caspian Sea and in 2018 only 1 tonne of sturgeon was caught, a 96 percent decrease from catches in 2007 (25.11 tonnes). The estimated fishery catch in the Russian Federation is likely grossly underestimated. Illegal fishing for sturgeon, and indeed from all littoral countries, is endemic. Additionally, there is an increasing problem with unreported catches of pike in the Russian Federation, because of increased market demand and increased levels of poaching. As a result, it is estimated that the unofficial catch could be over twice the legal catch (Environmental Protection Act, 2017).

In Kazakhstan, the 2006 fishery total in Table 29-2 is a decline from 2005 when catches were 16 151.4 tonnes. Previous catch estimates for the Ural–Caspian Basin included estimates of about 20 000 tonnes/year, for which the catch included sturgeon (200 to 300 tonnes), cyprinids and pikeperch (6 000 tonnes to 8 000 tonnes) and kilka (8 000 tonnes to 10 000 tonnes) (Mitrofanov and Mamilov, 2015). The fishery estimates in Table 29-2 are likely an underestimation of actual production. A World Bank report stated that actual production levels could be three or four times higher than those officially recorded. The World Bank also cautioned that most (if not all) of the fisheries under-report their catches to fisheries inspectors and in order to avoid taxes and other fees (World Bank, 2004), which is another indicator that the fisheries catches could be several times higher than reported figures.

Fish catches in the Iranian waters of the Caspian Sea in 2014 primarily constituted kilka (57 percent), followed by bony fish (42 percent) with sturgeons making up 1 percent of the catch. Total catches from the Caspian have declined from 46 435 tonnes in 2006, but on the whole catches have remained relatively stable at around 40 000 tonnes. The figure in Table 29-2 is likely an underestimation of actual fish catches in Islamic Republic of Iran, as illegal fishing is common and a large portion of catch (primarily sturgeon) goes unreported (FAO, 2015).

Status of the fisheries: catch trends

There has been a significant basin-wide decline in the fisheries, particularly in the catches of kilka. Historical catches between 1965 and 1990 averaged 323 000 tonnes, with peak catches during the 1970s of over 400 000 tonnes. But from 1990 catches decreased to about half that level and since 2000 the stock has virtually collapsed (Daskalov and Mamedov, 2007). The catch of kilka by the Russian Federation, Azerbaijan and Islamic Republic of Iran dropped from 182 700 tonnes in 2000 to 74 700 tonnes in 2001, even though the TAC was 300 000 tonnes. In Azerbaijan, between 2000 and 2004 the catch dropped 18 500 tonnes to 5 100 tonnes (Mamedov, 2006). Similarly, in Islamic Republic of Iran catches of kilka declined from 95 000 tonnes in 1999 to 16 700 tonnes in 2008 (FAO, 2015). Kilka stocks have been declining year on year, and populations appear unable to recover from their total recruitment failure in 2001, when 100 000 to 270 000 (10 percent to 40 percent of the stock) died (Tarasov, 2001). Also, kilka catches over the past few years have contained very few juveniles, an indicative sign of poor recruitment (Mamedov, 2006). The arrival of the comb jellyfish (*Mnemiopsis leidyi*) has been blamed for the drastic decline in kilka fisheries.

There has also been a basin-wide decline in sturgeon catches in the Caspian Sea. Historical catches of sturgeon averaged 26 000 tonnes between 1975 and 1983, but catches declined to 15 000/16 000 tonnes between 1990 and 1992 (Ovissipour and Rasco, 2012). Catches after 1993 collapsed and yielded no more than 8 000 tonnes (Abdolhay, 2004), possibly due to the cumulative effects of heavy fishing pressure during the 1970s and 1980s. In Islamic Republic of Iran between 1993 and 2009 sturgeon catches declined 90 percent from 1 710 tonnes to 178 tonnes (Ovissipour and Rasco, 2012). In the Russian Federation, catches of all sturgeons have drastically declined; between 2007 and 2014 catches of beluga, Russian, Persian and stellate sturgeons declined 50 percent, 75 percent, 87 percent and 75 percent, respectively. This has been attributed to regulated flow of the Volga River, reduction in spawning areas, intensive pollution, recent reduction in flows from the Volga River, increasing water temperature and illegal fishing and poaching (Environmental Protection Act, 2017).

Aquaculture

Artificial hatcheries have been developed by the littoral countries to improve and manage sturgeon stocks. There are 11 hatcheries in the Russian Federation, five in Islamic Republic of Iran and three in Azerbaijan. Islamic Republic of Iran has the most effective hatchery system with several facilities producing millions of sturgeon fingerlings annually. Mature fish are harvested from the wild and transferred to the hatchery for the recovery of eggs (Ovissipour and Rasco, 2012). In the Islamic Republic of Iran, in 2014 more than 287 million sturgeon fingerlings of various species were released into the southern part of the Caspian Sea and 650 tonnes of sturgeon were cultured in hatcheries (FAO, 2015).

In Azerbaijan, there are 13 hatcheries that produce juvenile sturgeon, kura salmon and cyprinids which are released into the Kura River and the Caspian Sea. The exact production quantity of these farms is not known, but it is rare for farms to produce optimally. This is due to management restrictions on the amount of fingerlings released, technical problems and financial restrictions which lower productivity (Salmonov *et al.,* 2013).

In the Russian Federation, there has been considerable variation in the production of sturgeon hatcheries. The number of stellate sturgeon juveniles released into the Volga–Caspian Basin declined from 6.69 million juveniles in 2007 to 1.73 million fingerlings in 2008 and there was no production in 2011. Production since 2014 has increased but production is a mere fraction of 2007 levels (129 000 juveniles). Hatchery production of Russian sturgeon was the largest in 2014, releasing 36.09 million juveniles into the Volga–Caspian Basin, an increase from the 16.2 million juveniles released in 2008. The juvenile survival of this species is said to be high, due to larger size at release (Environmental Protection Act, 2017).

Recreational fisheries

Sport fishing is hugely popular and well developed in the Russian Federation, but there is no information regarding the species caught, or the level of participation. Recreational fishing in Azerbaijan occurs in the Caspian Sea and other inland waters. Popular target species include pikeperch (*Sander lucioperca*), common carp (*Cyprinus carpio*), bream (*Abramis brama*), roach (*Rutiles rutiles*), vimba (*Vimba vimba*), asp (*Aspius aspius*), kutum (*Rutilus frisii*), mullet (*Liza auratus*), shemaya (*Chalcalburnus chalcoides*) and catfish (*Silurus glanis*). Recreational fishers can use several handlines but no more than seven hooks can be used at the same time. There is no monitoring or analysis of the amount of fish caught by recreational fishers, but the Society of Hunters and Fisheries estimates that at least 100 tonnes of fish are caught annually for recreation and catching sturgeon is prohibited (Salmonov *et al.,* 2013).

In Kazakhstan some 1 000 recreational fishers are officially registered as sport fishers, but there are no data available about the total number of recreational fishers in the country. The main target species are catfish, pikeperch, asp, salmonids and carp. Sport fishing can be undertaken using rods of any style or type with up to five rods per fisher (Timirkhanov *et al.,* 2010).

29.3 THREATS TO THE FISHERIES

Overexploitation and illegal fishing

Sturgeon species are long lived (up to 100 years) and late maturing (9 to 13 years) and therefore are particularly vulnerable to heavy levels of fishing (Billard and Lecointre, 2001). The introduction of plastic nets in the late 1950s in the Caspian Sea greatly increased the number of young sturgeons caught as by-catch. In the early 1970s the average weight of beluga females was 110 kg and in 1990 to 1991 this dropped to 57 kg (Khodorevskaya *et al.,* 1997), showing a reduction in size at maturity and harvest which are indicative signs of overfishing. The sex structure of the spawning stock of beluga has also changed, with females in 1991 constituting 24 percent of the stock as opposed to twice that in the 1960s, as females are harvested for their caviar and roe (Khodorevskaya *et al.,* 1997).

Illegal, unreported ad unregistered fishing is a major problem in the fisheries sector in each of the littoral countries and poaching cannot be controlled effectively (Abdolhay, 2004). Between 50 percent to 65 percent of the catch is thought to be illegal and in Kazakhstan the World Bank predicted that the actual harvest estimates of sturgeon could be three to four times higher than those officially reported (World Bank, 2004). Birstein (1996) considered the illegal catch of sturgeon from within the Caspian Sea to make no economic sense, as female sturgeons caught in the sea are not mature and caviar made from their roe is of inferior quality and cannot be sold legally. After the dissolution of the Union of Soviet Socialist Republics (USSR) in 1991, fishing pressure increased, as sea fishing, which had been illegal for 30 years, could start again, with substantial levels of illegal fishing (Khodorevskaya *et al.,* 1997; Abdolhay, 2004).

Water quality

The littoral countries of the Caspian Sea have experienced intensive industrial and agricultural developments in the watersheds around the Caspian Sea, especially oil extraction and mining; this has resulted in elevated levels of hydrocarbons, heavy metals, pesticides and organic waste in the waterbody (Pourkazemi, 2006). The toxicological situation of the coastal Caspian Sea grounds has already caused physiological and gonadal changes in sturgeons (Luk'yanenko *et al.* 1999). The concentrations of pesticides in fish have reached 2 mg/kg to 8 mg/kg and heavy metal concentrations (nickel and chromium) in sturgeon livers have exceeded maximum permissible concentrations by 10 to 13 times. Up to 90 percent of sturgeons has shown muscle delamination and shrinking of egg outer layers (Paveliva *et al.,* 1990).

Invasive species

Mnemiopsis leidyi is an actively hunting carnivorous ctenopheran (comb jellyfish) that feeds on zooplankton, fish eggs and fish larvae (Tzikhon-Lukanina, Reznichenko and Lukasheva, 1993). The arrival of *M. leidyi* resulted in the reduced biomass of zooplankton, mainly *Eurytemora grimmi* and *E. minor* which are the favoured prey of kilka, which dropped by a factor of 4-10 (Sokolskiy and Kamakin, 2004). Landings of anchovy dropped to one-third of their previous levels and was caused by both the elimination of the zooplankton, the normal food of pelagic fish, and by predation by *M. leidy* on floating fish eggs and early larvae (Shiganova and Bulgakova 2000). In 2000, the commercially exploitable biomass of kilka was estimated at 600 000 tonnes (Sedov and Paritskiy, 2001), but by 2004 this had fallen to some 164 000 tonnes (Sedov *et al.,* 2004) and continued to fall to 90 500 in 2005 (Mamedov, 2006).

29.4 FISHERIES MANAGEMENT

After the collapse of the USSR, no international agreement has been reached on the regulation of sturgeon catches among the countries bordering the Caspian Sea despite pressure from the international community. Therefore, there has been no effective fishery management system for the past 20 years and the associated control, monitoring and surveillance of fishing activities (Ovissipour and Rasco, 2012).

The 2018 Convention on the Legal Status of the Caspian Sea is a treaty signed by the Russian Federation, Kazakhstan, Azerbaijan, the Islamic Republic of Iran and Turkmenistan. Relevant to fisheries, the convention grants jurisdiction over 24 km (15 miles) of territorial waters to each neighbouring country, plus an additional 16 km (10 miles) of exclusive fishing rights adjacent to the territorial waters. The rest of the area of the Caspian Sea is considered common maritime space. The convention establishes a comprehensive fisheries regime, with each contracting state having exclusive rights to harvest in its fishery zone. The harvesting of biological resources in the 'common maritime space' is covered by a joint management regime, with contracting members dividing an agreed TAC into national quotas. If a contracting state is unable to use its quota fully, it may grant harvesting rights to other members state(s), but not to third states. The convention does not cover environmental issues.

National management strategies

In the absence of proper management for the whole Caspian Sea, the Islamic Republic of Iran invested public funds into a buy-back scheme, where fishing licences were repurchased by the state to control fishing pressure and prevent further erosion of exploited fish stocks. The Islamic Republic of Iran also has specially trained fishing guards who prevent illegal fishing at sea. Fisheries management objectives include stock rehabilitation, protecting natural nursery grounds, encouraging co-management, applying responsible fishery practices and applying selective fishing gear (FAO, 2015).

In Kazakhstan, there are no fishery management plans as such, but fishery management tools such as TAC and catch quotas are used (Timirkhanov, Chaikin and Makhambetov, 2007). Sweep nets, with a minimum mesh size, which are marked with the details of the net owner are the only legal fishing gear for sturgeon, and each fisher may only set one net at a time. Minimum size limits for *A. stellatus* and *A. gueldenstaedtii* are 105 cm and 110 cm, respectively (Raymakers, 2002). However, the ratio of males and females caught is not monitored or regulated, but the purchase price at landing sites is based on the fixed legal rate of caviar weight extracted per female (18.6 percent total body weight for *A. gueldenstaedtii* and 15.4 percent for *A. stellatus*) (TRAFFIC International 2010).

In Azerbaijan fisheries are regulated under the Law on Fisheries, 1998 which covers the legal basis, organization and management of fisheries and conservation of stocks. Regulations concerning fishing include rules of fishing and conservation of fish stocks, the place and timing of fishing, fishing gear and practices, measurement of fish and fines for illegal fishing (Salmonov *et al.,* 2007).

In the Russian Federation, fisheries are managed by the Law on Fishery Protection of Aquatic Biological Resources, 2004, which sets out TAC levels for all fishery stocks, not only sturgeon. Fishing rules are established separately for several major areas, including the Caspian Sea. Specific rules include closed areas, seasonal closures, limitations on particular gear, minimum mesh sizes, minimum allowable sizes of catch and allowable by-catch (FAO, 2007).

International management strategies

The trade of sturgeon is heavily regulated and controlled by CITES. Two species of sturgeon are listed in Appendix I of CITES; the remaining 25 are listed in Appendix II. With agreement from the Caspian Sea states in 2007, CITES reduced the combined catch quotas for sturgeon by an average of 20 percent relative to quotas in 2005. Since then, quotas have fallen and in 2011 the only country with an allowable catch quota was the Islamic Republic of Iran with 100 kg of caviar and 1 000 kg of meat for Persian sturgeon and 400 kg of caviar and 27 000 kg of meat for beluga sturgeon permitted (CITES, 2011). However, in recent years all the Caspian Range states have exceeded their annual export quotas for certain sturgeon species. As long as national legislation from Caspian Sea countries lacks effective regulation and control of illegal sturgeon catches, the present state of sturgeon stocks will continue to decline (TRAFFIC International, 2007).

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30 OB–IRTYSH RIVER

30.1 OVERVIEW

The Ob River is the seventh largest river in the world (Table 30-1) and the combined Ob–Irtysh system is the fourth largest river system in Asia. It flows across Siberia from its source in the Altai Mountains, emptying into the Arctic Ocean from the Kara Sea. The Ob River's main channel is entirely in the Russian Federation, although its tributaries extend into Kazakhstan, People's Republic of China and Mongolia. The total length of the Ob River is about 3 650 km, of which 4 percent to 10 percent is underlain by permafrost (Zhang *et al.,* 1999). The drainage basin includes many now-closed lake systems that historically belonged to the drainage basin. The Irtysh is the largest tributary of the Ob River, downstream of Semipalatinsk (Kazakhstan), the Irtysh flows through Western Siberia 1 000 km to Omsk where the channel splits into numerous branches. The Ob River receives water from a least seven other major tributaries, including the Severnaya Sos'va in the lower reaches and the Taz and Pur rivers in Western Siberia. The Ob River contributes about 15 percent of the total freshwater flow into the Arctic Ocean (Grabs, Fortmann and De Couuel, 2000; Shiklomanov *et al.,* 2000).

Table 30-1. Characteristics of the Ob–Irtysh River

Country	Area of the river (km²)	Percent area of the river in countries	Population of the river basin	Population density/km²
Russian Federation	2 180 457	72	21 065 453	10
Kazakhstan	698 324	23	4 725 038	7
People's Republic of China	90 933	3	630 045	7
Mongolia	55 589	2	32 798	1
Total	**3 025 304**	**100**	**26 453 334**	**6**

Fish diversity

FishBase reports that there are 11 species belonging to six families in the Ob–Irtysh River (FishBase, 2017). The fish fauna belong to the typical Siberian complex of Arctic cold-loving species, such as the tugun (*Coregonus tugun*)*,* Arctic cisco (*Coregonus autumnalis*) and charr (*Salvelinus alpinus*); boreal river species such as: the northern pike (*Esox lucius)*, roach (*Rutilus rutilus)*, common dace (*Leuciscus leuciscus)*, Prussian carp (*Carassius gibelio*) and Siberian sturgeon (*Acipenser baerii*) (Abell *et al.,* 2008). The Siberian sturgeon is classed as endangered by the IUCN due to dam construction and overfishing which has led to a decline in this species (Ruban and Zhu, 2010).

Fish introductions

To date, 22 alien fish species are known in the Ob–Irtysh River basin. Of them, nine species have formed self-reproducing populations and started self-spreading into natural waterbodies. These include pikeperch (*Sander lucioperca*), freshwater bream (*Abramis brama*), common carp (*Cyprinus carpio*), belica (*Leucaspius delineates*), bleak (*Alburnus alburnus*), stone moroko (*Pseudorasbora parva*), Amur sleeper (*Perccottus glenii*), Nikolsky's loach (*Misgurnus nikolskyi*) and the southern ninespine stickleback (*Pungitius platygaster*). Bream is considered the most successful of the introduced species in the Ob–Irtysh River, as it is common from Lake Teletskoe to the Gulf of Ob–Irtysh and its tributaries (Kolomin, 2011; Interesova, 2016).

30.2 FISHERIES OVERVIEW

The Ob–Irtysh River Basin is considered the most important inland freshwater fishing area in the Russian Federation (FAO, 2007). According to the Federal Law 'On Fishery and Protection of Aquatic Biological Resources' Russian fisheries are divided into three main categories which are industrial (mainly constitutes the marine sector, but also freshwater lakes of the Ob–Irtysh River), recreational and subsistence fishery of indigenous groups. Subsistence fishing occurs mainly in estuaries and rivers, and the indigenous fishers are legally bound to use the catch only for consumption and are not allowed to sell their catch (FAO, 2007). Common commercial catches consist of whitefish such as vendace, tugun, Arctic cisco, also pikeperch from the upper reaches of the Ob–Irtysh (Kuderskii, 2001), which constitutes around 11 percent of the catch in the Irtysh River (Kotov and Viser, 2000); bream is also commonly exploited, forming around 25 percent of the catch from the lower reaches of the Irtysh (Promotorova, 2000).

Fishing methods

Most of the inland commercial catch is caught using set nets, seine nets or small trawls on lakes (FAO, 2007).

Fish trade

Trading routes direct from the Ob–Irtysh River fisheries are not known, but the largest domestic markets for freshwater fish are major cities such as Moscow, St Petersburg and Kalingrad, which are the largest markets for fisheries products (FAO, 2007).

Estimated fisheries production

The catch estimates outlined in Table 30-2 for the Ob–Irtysh include catches from its tributaries (Tyumen, Tomsk, Novosibirsk, Omsk and Kurgan), the lakes of the Tyumen and Tomsk regions and the catch in the Ob bays of the Kara Sea. Most of the fish catch for the West Siberian region, of which the Ob–Irtysh River is the largest basin, comprises roach, northern pike, crucian carp, ide (orfe) and European perch (FAO, forthcoming). Catching Siberian sturgeon is prohibited except for artificial reproductive purposes; however, these figures are not included in catch statistics as the Siberian sturgeon is not a target species (Environmental Protection Act, 2017). The species breakdown of sturgeon catches was not available from the statistics, but in 2018, 8 tonnes of sturgeon not elsewhere identified (nei) were caught in the West Siberian region (FAO, forthcoming). The fishery production values are likely an underestimation of actual production levels, as illegal fishing and poaching are rife in the Russian Federation. The small area of the basin in People's Republic of China has an estimated fisheries production of 722 tonnes, based on the area of the basin in Chinese provinces.

Table 30-2. Fish production estimates for the Ob–Irtysh River

Waterbody		Catch estimate (tonnes)	Year	Reference
Russian Federation	Ob–Irtysh River	22 834	2018	FAO (forthcoming)
People's Republic of China	Xinjiang Uygur	722	2015	Zhao and Shen (2016)
Total		**23 556**		

Status of the fisheries: catch trends

The state of most valuable fish stocks within the basin are in a state of decline due to a long period of low water availability within the basin and high anthropogenic pressures, as well as reduction in the efficiency of feeding and reproduction (Environmental Protection Act, 2017).

Fish catches from the Ob–Irtysh River were relatively stable between 2008 and 2014 with a high catch of 22 130 tonnes in 2008 and a low of 20 330 tonnes in 2013. But overall catches seemed to have declined from around 39 860 tonnes in 1980 (Berka, 1990). Catches of whitefish from the region declined to a record low of 3 001 tonnes in 2015 (Litvinenko *et al.,* 2016). Arctic cisco catches have declined by 172 tonnes (90 percent) due to a sharp decline in river and estuarine catch. Catches of tugun have also decreased by 36 percent. Of particular concern is the decline in catches of *Coregonus muksun* which declined from 552 tonnes in 2004 to 51 tonnes in 2015 (Litvinenko *et al.*, 2016).

Aquaculture

To compensate for the negative impacts on whitefish there has been an increase in artificial propagation activities. The current approach of stocking and aquaculture in the Ob River Basin is through mass-stocking of whitefish larvae in floodplain reservoirs after ice breakup. The average survival rate of stocked larvae is 40 percent and the total number of juveniles grown this way reached 106 million in 2009. Ninety-two million juveniles were released into the Ob River Basin in 2015. Commercial whitefish farming in lakes is becoming widespread with the most commonly farmed species being *Coregonus peled*; about 3 000 tonnes of farmed fish are transported to the Ob River annually from Siberia (Litvinenko *et al.,* 2016).

Recreational fishing

Recreational fishing is considered well developed in the Russian Federation, but it is difficult to distinguish from subsistence fishing (FAO, 2007). The numbers and scale of recreational fishing in the Ob–Irtysh River Basin are unknown, but common carp is mainly targeted as it is not numerous in the Ob River (Interesova, 2016).

30.3 THREATS TO THE FISHERY

Water quality

Pollution of whitefish feeding and wintering zones by the oil industry is a possible cause of the decline in whitefish catches (Litvinenko *et al.,* 2016). High concentrations of heavy metals coming from local industry from cities that line the river pose a serious threat to water quality. Industrial waste in the Irtysh River amounts to around 30 million tonnes per year (Hrkal *et al.,* 2006).

Habitat modification

Lower water levels and water flow that occurred in the basin from 2008 to 2013 caused a decline in the state of fish stocks from the basin (Environmental Protection Act, 2017). The Ob–Irtysh River Basin has undergone hydrological change through the construction of a large reservoir and three mid-sized dams that were built between the 1950s and 1980s (Yang, Ye, and Shiklomanov, 2004). These dams will have similar impacts on fish as reported from other rivers with hydroelectric dams.

30.4 FISHERIES MANAGEMENT

National management strategies

Fisheries in the Russian Federation are regulated by the Federal Law on Fishery and Protection of Aquatic Biological Resources, 2004. A few provisions of this law relate specifically to inland fisheries, i.e. fishing rules for various catchments or river systems. Specific regulations enforce closed areas, seasonal closures, gear restrictions, minimum mesh sizes and minimum catch sizes (FAO, 2007).

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31 URAL RIVER

31.1 OVERVIEW

The Ural River is 2 428 km in length and the third largest river in Europe after the Volga and the Danube rivers (Table 31-1). The river is sourced in the Ural Mountains near Mount Kruglaya. It flows through the Russian Federation and through Kazakhstan into the Caspian Sea. The river is mostly fed by melting snow (60 percent to 70 percent) and most of the discharge (maximum 14 000 m^3/s) occurs during the spring floods. During this time, the river widens to over 10 km near Uralsk (West Kazakhstan) and the river level fluctuates from 3 m to 10 m. The Ural River receives water from tributaries, the largest of which is the Sakmara River, but others are the Chaga, Barbastau and the Or rivers (Bogutskaya, 2015).

Table 31-1. Characteristics of the Ural River

Country	Area of river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
Russian Federation	121 335	56	2 358 598	19
Kazakhstan	93 833	44	1 187 126	13
Total	**215 169**	**100**	**3 545 725**	**16**

Fish diversity

Fish diversity in the Ural River is outlined in Table 31-2. Species diversity is similar to that of the Caspian Sea and the Volga River. One of the most distinguishing features of the Ural River is that it is the only major river still used for sturgeon spawning migrations (Bogutskaya, 2015). All sturgeon species present in the Ural River are listed as either vulnerable (*Acipenser ruthenus*) or critically endangered (*A. stellatus*, *A. nudiventris* and *Huso huso*) by the IUCN (IUCN, 2017). The river was also once habitat for the whitefish inconnu (*Stenodus leucichthys*) but this species has not been recorded in the Ural River since the 1960s and is classed as extinct in the Wild (IUCN, 2017). There are no documented fish introductions directly into the Ural River except for grass carp (*Ctenopharyngodon idella*), of which there is a small self-recruiting population (Mitrofanov, 2005) that has not produced any significant impacts on the existing ecosystem (Mitrofanov and Mitrofanov, 2015).

Table 31-2. Fish diversity in the Ural River

River	Total species	Endemic species	Introduced species
Ural River	53	0	1

Sources: Mitrofanov (2005); FishBase (2017)

31.2 FISHERIES OVERVIEW

Fisheries production in Kazakhstan mainly comes from the Lower Ural River, accounting for 51 percent of national production. The river is of limited importance for commercial fisheries but is important for recreational fishing. There is some element of subsistence fishing in the Ural River, which is mainly known as subsistence–recreational fishing and is conducted in all waterbodies of Kazakhstan. However, it is not possible to estimate how many people fish for food security (Timirkhanov *et al.,* 2010). The main species caught are sturgeon (*A. stellatus, A. gueldenstaedti* and *H. huso*) and roach (*Rutilus rutilus*) in the Ural Basin (FAO, 2001). All the sturgeon species that ascend the Ural River for spawning have a high commercial value (Timirkhanov *et al.,* 2010), with beluga (*H. huso*) caviar in 2009 fetching up to USD 8 000/kg, which was an incentive for illegal fishing (Doukakis *et al.,* 2009). Illegal fishing and poaching are endemic in Kazakhstan and the Russian Federation, principally for sturgeon species. A ban on all fishing of fringebarbel sturgeon (*A. nudiventris*) was imposed in the Ural River in 2002, due to the low abundance of the species. However, there was an exception for restocking and research purposes (Timirkhanov *et al.,* 2010).

Fishing methods

Fishing rods of any style or type with up to five rods per fisher are used. Outside of recreational areas, harpoon guns can also be used. Other methods such as fishing with seine nets are only allowed on lakes, but trawl fishing and electrofishing and fishing with poisons are prohibited (FAO, 2001).

Fish trade

The value of the Ural River fishery is not known, but the sturgeon and caviar are exported to other European countries. Official catch estimates suggest fisheries represent 0.2 percent of the GDP (Timirkhanov *et al.,* 2010).

Employment

While some 1 000 recreational fishers are officially registered as sport fishers, there are no data on the total number of fishers in the Ural Basin or in Kazakhstan as a whole. FAO (2001) reported that there were around 5 200 active fishers in the sector and official statistics from the Ministry of Agriculture in 2006 stated that participation in fishing was as high, with 17 300 fishers (Timirkhanov, Chaikin and Makhambetova, 2007). However, the World Bank estimates that the real number of fishers could be as high as 110 000 (Timirkhanov *et al.,* 2010).

Estimated fisheries production

Table 31-3 indicates the estimated fisheries production for the Ural River. There was no information regarding fishery catches in the Russian Federation. Previous catch estimates were about 20 000 tonnes/year from the Ural–Caspian Basin in Kazakhstan, which included sturgeon (200 tonnes to 300 tonnes), cyprinids and pikeperch (6 000 tonnes to 8 000 tonnes) and kilkas (*Clupeonella*) (8 000 tonnes to 10 000 tonnes) (Mitrofanov and Mitrofanov, 2015). FAO (2001) suggested that the average catch between 1998 and 2001 was 22 220 tonnes from the Lower Ural River. The figure in Table 31-3 is not likely to be representative of actual catches in the Ural River, mainly because the fishery estimate includes a large portion of the Caspian Sea. In addition, the World Bank (2004) reported that most (if not all) of the fisheries under-report their catch to both the statistics agency and the fish inspectors in order to avoid taxes and other fees. Additionally, illegal fish harvests are not recorded with most illegal fishing occurring away from formal markets. Fisheries production in Kazakhstan could therefore be three or four times higher than that officially recorded (Timirkhanov *et al.,* 2010).

Table 31-3. Estimated fisheries production for the Ural River

Country	Catch estimate (tonnes)	Year	Reference
Russian Federation	n.a.		
Kazakhstan	13 631	2006	Timirkhanov *et al.* (2010)

Note: The Kazakhstan fishery total includes its portion of the Caspian Sea.

Status of the fishery: catch trend

Sturgeon catches have declined drastically over the last 30 years. In the Ural–Caspian Basin in 1975, the sturgeon catch was 8 200 tonnes and in 2007 this figure had dropped to 94 tonnes. In Kazakhstan sturgeon catches were generally around 200 tonnes to 300 tonnes (the catch quota was 215 tonnes), but previous catches were as high as 5 000 tonnes to 8 000 tonnes (Mitrofanov and Mitrofanov, 2015). The Ural River is the only major river still used for sturgeon spawning in the Caspian Sea Basin (Bogutskaya, 2015). Since the 1970s the numbers of spawning stellate sturgeon decreased from 1.5 million to around 20 000 to 25 000 individuals in 2007 (Bokova, 2008). Landings of beluga sturgeon in the Ural River peaked at over 750 tonnes in the mid-1960s and decreased to 27 tonnes in 2007 (Doukakis *et al.,* 2009).

As of 2002, only 2 500 beluga sturgeon had spawned in the Ural River, whereas historically tens of thousands spawned there annually. The status of the sturgeon fishery is exacerbated by no data on the number of individual beluga (or other sturgeon species) in the Ural River (Doukakis *et al.,* 2009).

Aquaculture

To compensate for the losses of sturgeon species, hatcheries were established. In the Ural River, the Atyrau Sturgeon Hatchery is the main hatchery. The target capacity is 7 million sturgeon fingerlings annually. The hatchery does not have any domestic brood stock but instead captures wild, mature breeding sturgeons during their spawning run. Russian sturgeon, stellate sturgeon, beluga, fringebarbel sturgeon and sterlet sturgeon are all reproduced by the Atyrau Hatchery, but the prime species is the stellate sturgeon (representing 65 percent of released fingerlings) (Timirkhanov *et al.,* 2010).

Recreational fisheries

Recreational fishing is considered the main fishing activity in the Ural River. The main species targeted by recreational or subsistence–recreational fishers are catfish, pikeperch, pike, salmonids (rainbow trout, grayling and lenok), sturgeon and carp (crucian, silver) (Timirkhanov *et al.,* 2010). A small number of foreign visitors come to Kazakhstan for sport fishing, but there are no data on the number of fishers. The Union of Societies of Hunters estimated registered catch by recreational fishers in 2008 in Kazakhstan at 916 tonnes (Thorpe and van Anrooy, 2010).

31.3 THREATS TO THE FISHERIES

Overfishing and illegal unreported and unregulated catches

Sturgeon live up to 100 years and are late maturing (9 to 13 years) and are particularly vulnerable to heavy levels of fishing (Billard and Lecointre, 2001). The Ural River beluga fishery is dominated by first-time spawners. The lack of older age classes in the spawning population is a classic sign of unsustainable levels of fishing and Doukakis *et al.* (2009) estimated that harvest rates were four to five times higher than rates that would sustain the population of beluga sturgeons. Overfishing and poaching in the native range of the stellate sturgeon are the primary causes of population decline of the species. Based on catch data, the number of individuals migrating to the Ural River has declined by 80 percent over the last 30 years (Qiwei, 2009). Natural recruitment has declined dramatically; in 1977 there were an estimated 1.33 million migrating individuals, but only 377 000 in 1988 of which 90 000 were spawners (Billard and Lecointre, 2001); by 1992 the Ural River population was one-third of the number observed in 1986 (Khodorevskaya *et al.,* 1997).

Since the dissolution of the USSR, the abundance, spawning biomass and total population have been declining due to increased intensity of poaching. Poaching for caviar is considered the biggest threat to sturgeon. Actual production levels of sturgeon in the Ural River could be three of four times higher than those officially recorded and represent a potential revenue loss to the Kazakhstan economy of between USD 1.5 million to USD 2.3 million (Timirkhanov *et al.,* 2010). Even though the number of poachers caught increased by 20 percent between 2005 and 2006 (8 499 to 10 023) and the number of fines increased by 300 percent, there is still weak enforcement of fishing regulations and a lack of fish inspectors. Furthermore, the fines imposed for poaching are not an incentive to fish legally as the economic benefits of illegal sturgeon fishing outweigh any fine currently imposed (TED, 2017).

31.4 FISHERIES MANAGEMENT

National management strategies

Sturgeon species are not fully protected within their habitat, but licences are required in most countries to fish for sturgeon (Kottelat, Gesner and Freyhof, 2009). Sweep nets, with a minimum mesh size, that are marked with the details of the net owner, are the only legal fishing gear for sturgeon, and each fisher may only set one net at a time. Sturgeon fishing grounds are limited to 12 sites in the Ural River and fishing restrictions are imposed between the winter and spring. Minimum catch limits for *A. stellatus* and *A. gueldenstaedtii* are 105 cm and 110 cm, respectively (Raymakers, 2002). However, the ratio of males and females caught is not monitored or regulated; the purchase price at landing sites is based on the fixed legal rate of caviar weight extracted per female (18.6 percent total body weight for *A. gueldenstaedtii* and 15.4 percent for *A. stellatus*) (TRAFFIC International, IUCN and UNEP–WCMC, 2000).

International management strategies

The trade of sturgeon caught in the Ural River is strictly regulated and controlled under CITES. Two species of sturgeons are listed in Appendix I of CITES; the remaining 25 are in Appendix II. With agreement from the Caspian Sea states in 2007, CITES reduced the combined catch quotas for sturgeon by an average of 20 percent relative to quotas in 2005. In Kazakhstan, this affected catches and exports of Russian, stellate and beluga sturgeons. However, in recent years all the Caspian Range states have exceeded their annual export quotas for sturgeon species. However, as long as national legislation from Caspian countries lacks effective regulation and control of illegal sturgeon catches, sturgeon stocks will continue to decline (TRAFFIC International, 2007).

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32 VOLGA RIVER

32.1 OVERVIEW

The Volga River (Table 32-1) is 3 690 km long with an average annual discharge of 8 103 m^3/s. It is the largest river in Europe and the sixteenth largest in the world. (Litvinov *et al.,* 2009). Snowmelt accounts for 60 percent of the river's annual discharge, with underground water making up 30 percent and rainwater 10 percent. Rising in the Valdai Hills in northwest Moscow the Volga discharges into the Caspian Sea, and provides more than 75 percent of the total flow into the sea. The Volga River receives water from some 200 tributaries, the main ones being the Kama, Oka, Sura, Moksha and the Tsna rivers. The Volga River is divided into three parts: the Upper Volga (from its source to the confluence with the Oka River); the Middle Volga (from the Oka to the Kama River); and the Lower Volga (from the Kama River to the Caspian Sea). A cascade of reservoir dams in the Middle Volga has changed the natural flow regime of the Lower Volga downstream of Volgograd (Middelkoop *et al.,* 2005). The Volga is a major navigation corridor carrying more than half of all Russian Federation inland freight; as such, typical riverine habitats remain only in the upper reaches and in some tributaries (Bogutskaya, 2015).

Table 32-1. Characteristics of the Volga River

Country	Area of the basin (km^2)	Percent area of the river in the country	Population of the river basin	Population density/km^2
Russian Federation	1 474 076	100	61 532 762	41.74

Fish diversity

Fish diversity in the Volga River is outlined in Table 32-2, mainly species from the Cyprinidae (38 species) and Gobiidae families (19 species) (FishBase, 2017). The construction of dams and reservoirs has strongly influenced fish diversity. Anadromous species, Caspian lamprey, shad and sturgeons lost most of their natural spawning grounds. Rheophilic species such as dace (*Leuciscus leuciscus*), chub (*Squalius cephalus*) and gudgeon (*Gobio gobio*), either adapted to reproduce in channels or disappeared completely.

The Volga River is also habitat for seven sturgeon species. These species of sturgeon include the stellate sturgeon (*A. stellatus*), Russian sturgeon (*A. gueldenstaedtii*), fringebarbel sturgeon (*A. nudiventris*), Persian sturgeon (*A. persicus*) and beluga sturgeon (*Huso huso*), which are all classed as critically endangered. Also present are the Siberian sturgeon (*A. baerii*) and the sterlet sturgeon (*A. ruthenus*) classed as endangered and vulnerable, respectively (IUCN, 2016).

Table 32-2. Fish diversity in the Volga River

River	Total species	Endemic species	Introduced species
Volga River	65–118	0	3

Sources: Bogutskaya (2015); FishBase (2017).

32.2 FISHERIES OVERVIEW

The Volga River supports a commercial fishery on the floodplain lakes and the Volga River channel. Fish catches are correlated with the annual flood cycles, because of large snowmelt in the Upper Volga (Górski *et al.,* 2012). The catch composition differs between the Volga channel and the floodplain lakes. In the Volga channel there is generally a higher catch of rheophilic species, whereas in the floodplain lakes, limnophilic rudd is more abundant than in the main channel and a higher number of eurytopic species (carp, rudd, pike and white bream) make up the commercial catch (Górski *et al.,* 2012). Thirteen species make up more than 95 percent of the commercial catches, which include the blue, white and common bream, gibel carp, pike, sabrefish, perch, roach, pikeperch, rudd and wels catfish. In addition, populations of stellate sturgeon, Russian sturgeon and beluga sturgeon have commercial importance (Bogutskaya, 2015).

Fishing methods

Most inland commercial catches in the Russian Federation are obtained using set nets, but other gear such as seine nets (big rivers or lakes) and small trawls (big lakes) are also common (FAO, 2007).

Fish trade

Direct trading routes for commercial fisheries catches from the Volga River are not known. Except for sturgeon black caviar, which is widely exported, most domestic fisheries catch is marketed fresh or frozen and transported to large cities within the Russian Federation (FAO, 2007).

Employment

There are no estimates on participation in fisheries activities on the Volga River; however, the general lack of fishing regulations and control, and a high incidence of illegal fishing and poaching would suggest a considerable fishing effort occurs.

Estimated fisheries production

Table 32-3 indicates the estimated fisheries production of the Volga River and associated reservoirs in 2018 from delineated fisheries data. Catches from the Volgograd Reservoir generally increased from 2 600 tonnes in 2013 to 3 931 tonnes in 2018 (Environmental Protection Act, 2017; FAO forthcoming), with main catches being bream, roach, carp, perch, pike and catfish, accounting for 77 percent of the catch. The sturgeon fishery decreased dramatically from 2 690 tonnes in 2009 to only 8 tonnes in 2018 (Environmental Protection Act, 2017; FAO forthcoming). Illegal black market trade of black caviar from sturgeon species is a lucrative business and illegal harvest exceeds legal catch by several orders of magnitude (Vaisman and Raymakers, 2001); as such the estimated fish catch in Table 32-3 is likely an underestimation of actual production due to the scale of illegal fishing.

Table 32-3. Commercial fishery production estimates for the Volga River

Waterbodies	Fish catch	Year	Reference
Volga River and associated reservoirs	68 200	2018	FAO (forthcoming)
Total	**68 200**		

Status of the fisheries: catch trends

Since the impoundment of the Volga River in the 1960s, fish catches have declined on the main Volga channel and the floodplain lakes. Overall catches of floodplain species have increased and catches of riverine species have decreased. This can be attributed to an increase of gibel carp and decrease of blue bream after 1990 (Górski *et al.,* 2012). Changes in abundance and distribution of nearly all Volga species has taken place, for instance a reduction in about 25 riverine species has been observed, while an increase in area for nearly ten lacustrine species has occurred (Bogutskaya, 2015).

Conversely, catches of Caspian cisco and sturgeon have dramatically declined since the 1980s due to the loss of spawning grounds; both populations are now reliant on artificial reproduction or stocking and native Caspian cisco are reportedly extinct (Bogutskaya, 2015). High fishing pressure led to a decline in sturgeon catches in the 1940s; with an increase in the 1970s, commercial catches increased to 20 000 tonnes. However, since the 1980s sturgeons have suffered population collapse and catches have declined ten-fold; in 2004 the commercial sturgeon catch was about 400 tonnes, including 153 tonnes for research purposes and for artificial reproduction (Malstev, 2009).

Aquaculture

To tackle the declining stocks of sturgeon, stocking of sturgeon species through artificial propagation began in 1957. The degraded water quality of the Volga River makes fish farming on the main channel and some tributaries unsuitable. Stocking and aquaculture approaches in the Volga involve the use of earthen ponds, which are stocked just prior to the initiation of feeding, at a density of 60 000 to 75 000 fish per hectare. The rearing period continues for 30 to 40 days, the survival rate of the harvest is 56 percent to 60 percent and fingerling size is 2 g to 3 g (Abdolhay, 2004). It is estimated that between 30 percent to 50 percent of the Volga sturgeon populations comes from stocking (Khodorevskaya *et al.,* 2002).

Recreational fishing

Recreational fishing is a popular pastime in the Russian Federation; however, catches are difficult to separate from subsistence fishing as they are governed by the same fishing rules. There has been an increase in organized tourist fishing, particularly in the Lower Volga Basin. The most targeted fish are cyprinids and perches (FAO, 2007).

32.3 THREATS TO THE FISHERIES

Water quality

Over half of Russian Federation's industry is located within the Volga drainage system and major industrial complexes have had adverse ecological consequences on the river as it comes under anthropogenic pressure. The river shows contamination by organic and inorganic toxic substances such as petrochemicals, heavy metals, pesticides and untreated sewage. Research has indicated muscle atrophy, tumour growth and abnormal gonad development in fish populations because of toxic contamination from increased pollution levels. Between 1965 and 1988 there were 908 fish kills caused by discharges of pollutants (Rozenberg and Krasnoshchekov, 1996). Accumulation of pollutants in sturgeon populations has led to high incidences of muscle degradation, and in 1990, 100 percent of eggs taken from females in the Lower Volga reaches showed abnormalities and 100 percent of embryos was nonviable (Khodorevskaya *et al.,* 1997).

Overfishing

Another threat to the survival of Volga fish species, particularly the threatened sturgeon, is uncontrolled overfishing and a sharp increase in the level of poaching. Particularly after the breakup of the USSR, the absence of common fishery agreements combined with political and economic instability caused a sharp increase in poaching in the Volga River. Unfortunately, the scale of poaching occurred at a time of decreased effort to replenish sturgeon stocks with artificially reared juveniles (Khodorevskaya *et al.,* 1997). The numbers of Russian sturgeon released from hatcheries increased from 20 million to 40 million from 1980 to 1983. However, this was not enough to stabilize populations in the Volga; artificial reproduction in general has failed to compensate for the stock losses caused by overfishing, pollution and other anthropogenic stressors (Khodorevskaya *et al.,* 1997). Furthermore, the rising global demand for caviar is responsible for increased overfishing and the creation of a black market for sturgeon, particularly for beluga sturgeon caviar. The large economic incentive for selling beluga caviar (it can fetch USD 30 690/kg) has led to widespread corruption amongst river guards who are employed to stop poaching (TED, 2017).

Habitat modifications

Hydroelectric dam construction and channelization of the Volga River has meant that typical riverine habitats only remain in the upper reaches and in the forewaters of dams and account for no more than 1 percent of the total surface area of the basin. Commercial catches and distribution of fish species showed a considerable decrease in both the Volga channel and the Volga floodplain after construction of the Volgograd Dam was completed (Górski *et al.,* 2012). There has been a considerable change in the distribution of at least 35 species, with populations of rheophilic and limnophilic species having to adapt to reproduce in channels, but their numbers have diminished significantly or disappeared altogether from the main channel (Bogutskaya, 2015). Building hydroelectric dams has had a considerable impact on sturgeon populations throughout the basin. Declines in commercial catches of beluga and Russian sturgeons occurred after the construction of dams. Both beluga and Russian sturgeon could no longer reach their historic spawning grounds as their movements were blocked by the Volgograd Dam; it was estimated that as much as 80 percent of the historic spawning grounds for Russian sturgeon became unavailable. This species is now forced to spawn downriver of the Volgograd Dam, in areas not as suited to their spawning requirements, which has resulted in decreases in natural reproduction and changes in the population structure (Khodorevskaya *et al.,* 1997).

32.4 FISHERIES MANAGEMENT

Institutional constraints are direct causes of the governmental mismanagement of Russian Federation fisheries, with frequent restructuring of governmental institutions responsible for fishery management and control. The lack of awareness of regulations, weak enforcement and corruption are other reasons for the high participation in illegal fishing activities (FAO, 2007).

National management strategies

Fisheries were tightly controlled during the Soviet era, with catch quotas, seasonal closures and gear restrictions (Secor *et al.,* 2000). The Federal Law on Fishery and Protection of Aquatic Biological Resources, 2004 regulates fisheries in the Russian Federation. Some regulations apply to inland fisheries, which mainly consist of fishing rules for various catchments and gear restrictions (FAO, 2007).

In recognition of the imperilled sturgeon populations, all sturgeon species within the Volga system were placed under CITES Appendix 2, restricting the trade of all sturgeon parts including caviar. CITES has adopted a series of recommendations outlining conservation measures for sturgeon species, including enhanced fishery management, regional coordination and control of illegal trade. Implementation of these recommendations has been problematic, but overall, greater trade regulation and scrutiny of fish management have resulted. However, problems with CITES compliance have resulted in temporary fishery closures, trade bans and zero quotas, but long-term bans have never been implemented and many recommendations remain outstanding, and illegal trade in sturgeon black caviar persists (Pikitch *et al.,* 2005).

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33 DANUBE RIVER

33.1 OVERVIEW

The Danube is the second longest river in Europe after the Volga and is the most multinational river in the world, spanning 19 countries (Table 33-1). The river covers a length of 2 850 km from its source in the Black Forest Mountains of Germany to its mouth on the Black Sea. The Danube is a principal resource for industry, agriculture, transport and power generation; approximately 60 of its 300 tributaries are navigable (ICPDR, 2004). The river is split into three sections: the Upper Danube from its source to the Hungarian Gates in the Austrian Alps; the Middle Danube runs from the Hungarian Gates to the Iron Gates in Southern Romania; and the Lower Danube flows from the Iron Gates to the delta estuary with the Black Sea. In its lower reaches the river is 1 km to 2 km wide and forms a vast delta (4 500 km^2) which is part of Ramsar Wetlands of International Importance (ICPDR, 2004; Bogutskaya and Hales, 2015). The Upper Danube has been highly modified by dams, navigation channels and bank construction for flood protection.

Table 33-1. Characteristics of the Danube River

Country	Area of the basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
Albania	137	0.02	1 199	9
Austria	80 645	10.09	8 151 746	101
Bosnia and Herzegovina	37 785	4.73	3 314 517	88
Bulgaria	47 529	5.94	3 305 533	70
Croatia	32 361	4.05	2 834 258	88
Czechia	21 709	2.72	2 748 372	127
Germany	56 080	7.01	9 823 595	175
Hungary	93 127	11.65	9 860 770	106
Italy	708	0.09	16 883	24
Montenegro	6 800	0.85	187 245	28
North Macedonia	51	0.01	7 041	139
Poland	488	0.06	39 178	87
Republic of Moldova	12 248	1.53	1 029 096	84
Romania	232 481	29.08	19 130 354	82
Serbia	81 891	10.24	7 896 126	96
Slovakia	47 104	5.89	5 210 179	111
Slovenia	16 277	2.04	1 830 163	112
Switzerland	1 802	0.23	31 123	17
Ukraine	30 358	3.80	2 744 863	90
Total	**799 542**	**100**	**78 162 241**	**86**

Fish diversity

According to FishBase, the Danube contains 119 species including 5 endemic and 15 introduced species (Table 33-2). Endemic species include Danubian brook lamprey (*Eudontomyzon vladykovi*) and European mudminnow (*Umbra krameri*). Sturgeons are a flagship species of the Danube, but most species, except the sterlet sturgeon (*Acipenser ruthenus*), are almost extinct and populations are dependent on artificial reproduction. Russian sturgeon (*A. gueldenstaedtii)*, beluga sturgeon (*Huso huso)* and stellate sturgeon

(*A. stellatus*) are extinct in the Upper Danube and all other sturgeon species in the Middle and Lower Danube are highly endangered.

Introduced species consist of Mozambique tilapia (*Oreochromis mossambicus*), weatherfish (*Misgurnus fossilis*), grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichythys molitrix*), stone moroko (*Pseudorasbora parva*) mosquitofish (*Gambusia affinis*), peled (*Coregonus peled*), sea trout (*Salmo trutta*) and brook trout (*Salvelinus fontinalis*) (FishBase, 2017).

Table 33-2. Fish diversity of the Danube River

River	Total species	Endemic species	Introduced species
Danube	119	5	15

Source: FishBase (2017).

Fisheries overview

The Danube supports both commercial and recreational fisheries depending on the country. Germany, Austria and Slovakia do not contain any substantial commercial fisheries, but recreational fisheries play a major role in fishery catches. Commercial fisheries are more important in Hungary, Romania, Bulgaria, Serbia and Ukraine, where the large floodplains support both commercial and recreational fisheries (Schiemer *et al.,* 2004). The largest fishery on the Danube is situated in Serbia and Romania, but the value of this fishery and many others over the Danube has declined due to the construction of dams within the basin. About 40 species are attractive for commercial and recreational fisheries: common bream (*Abramis brama*), zander (*Sander lucioperca*), common barbell (*Barbus barbus*), sterlet sturgeon (*Acipenser ruthenus*), common carp (*Cyprinus carpio*), northern pike (*Esox lucius*), Volga pikeperch (*Sander volgensis*), asp (*Aspius aspius*) and tench (*Tinca tinca*) (Schiemer *et al.,* 2004; Smederevac-Lalić *et al.,* 2012). In Serbia and Hungary, commercial catches consist of 40 percent to 70 percent of common bream, common barbell and Prussian carp, whereas in Germany recreational catches consist of *Coregonus* spp., perch, northern pike and common carp (Smederevac-Lalić *et al.,* 2012). The sturgeon fishery has drastically declined since the 1970s and the quality of catch has shown a continuous decline due to poor connectivity between the river and its floodplain, and blockage of migration corridors (Schiemer *et al.,* 2004).

Fishing methods

Generally, permitted fishing methods throughout the basin are largely the same. Allowable gear types are those using wind, gillnets, seine nets, rods and trawls on larger bodies of water (European Commission, 2009). However, there are some discrepancies in gear usage; for instance the use of destructive unbaited hooks is prohibited in Romania and Ukraine, but is allowed in parts of Bulgaria and Serbia to catch sturgeon (Schiemer *et al.,* 2004).

Fish trade

The direct trade routes from Danube fisheries are not known. But most of the catch from the Danube region is consumed within the country of origin, and exports are generally small. Since 2000, fish exports from Bulgaria have been prohibited (FAO, 2002). But in 2008 in Romania, the gibel carp catch, which dominated the fisheries catch from the Danube, was valued at EUR 3.304 million (European Commission, 2009).

Employment

Table 33-3 indicates the participation in commercial and recreational fisheries activities within the Danube River Basin. For most countries, participation data on fisheries were not available. For instance, in Germany, a fishing licence is not required in every state, therefore any valuation of angler numbers is likely an underestimation (Aas, 2008). In addition, in Austria, each province issues fishing licences, but most of the recreational fishing is conducted on private fishing areas, where licences are issued by individuals or associations, for which numbers are unavailable (Dill, 1990).

In Bulgaria, the number of commercial fishers in the Danube Delta increased from 363 in 1986 to 2 000 in 1998 (FAO, 2002). In Slovakia, most recreational fishing is conducted in the Danube River Basin, but no definitive estimate for the number of recreational anglers was available; country-wide there are roughly 120 000 anglers (Novomeská and Kováč, 2016). In Romania, the commercial fishing sector employs 1 510 people; new rules on permit issue, which do not restrict gear use, have generated increased fishing capacity. Men comprise 98 percent of the commercial labour force. Also, 4 500 family fishers have the right to fish for 3 kg/capita and account for 3 400 tonnes of fish (European Commission, 2009).

Table 33-3. Participation in fisheries activities on the Danube River

Country	Commercial fisheries		Recreational fisheries	
	Male	*Female*	*Male*	*Female*
Croatia		19	360	23
Romania	1 488	10		
Bulgaria		2 000		
Hungary		500		
Serbia		442		19 981
Total		**4 459**		**20 364**

Sources: Matulić *et al.* (2010); Mitchell, Vanberg and Sipponen (2010); Smederevac-Lalić *et al.* (2011).

Estimated fisheries production

Table 33-4 gives the estimated inland fisheries catches from Danube countries for which data could be found. Sommerwerk *et al.* (2009) stated that commercial and recreational fisheries catches in the Danube amounted to approximately 30 000 tonnes. Presently, there is no commercial fishery in the Danube River in the Czech Republic and Slovakia.

In Romania, commercial catches have shown a declining trend. Fish catches in 2008 were 32 percent lower than the fish catch in 2007; this was due in part to the economic crisis at the time and changes in the administration of fishery resources, which led to a reduction in fish catch records and a proliferation of illegal fishing (European Commission, 2009). Also, fish stocks were being overexploited, such as bream, roach, catfish, carp, rudd and grey mullet. There was also a substantial amount of unreported fishing in Romania (European Commission, 2009). In this context and due to the scale of unreported catches, the estimated fish catches in Table 33-4 for 2008 do not reflect the reality.

In Bulgaria, commercial fishing on inland waterbodies is not permitted except on the Danube River. In 2014, the total catch from the Danube River was 14 284 tonnes, which represented 1.67 percent of the total fish catch (European Maritime and Fisheries Fund, 2016).

In Serbia, inland fisheries catch from the Danube River has shown a significant upward trend since 2005 (in 2003 commercial catches were 428 tonnes, compared to 1 026 tonnes in 2010); however this is unlikely to be a result of increased commercial fishing effort. In 2005, responsibility for catch statistics collection shifted from national to local levels, which improved the quality of collection procedures; also in 2005 an electronic statistics register was established and a more rigorous data collection procedure was implemented (Smederevac-Lalić, 2013). As the number of commercial anglers has decreased and fishing effort and methods have remained the same, the increase in total catch is not due to an increase in commercial fishing catch, but rather improvement in catch data collection. In the last ten years, fishers have not been required by law to report their fish catches and the level of poaching and illegal fishing has been increasing, suggesting that the catch data may not be reliable (Smederevac-Lalić *et al.,* 2011).

Table 33-4. Commercial fishery production estimates for the Danube River

Country	Fish catch (tonnes)	Year	Reference
Romania	2 507	2008	European Commission (2009)
Bulgaria	14 284	2014	European Maritime and Fisheries Fund (2016)
Serbia	1 026	2010	Statistical Office of the Republic of Serbia
Hungary	6 472	2013	Fisheries Operational Programme of Hungary (2015)
Ukraine	4 88.2	2005	Schmutz (2006)
Croatia	8.64	n/a	Ĉaldarović (2006)
Total	**24 786**		

Status of the fisheries: catch trends

Historically, the average annual catch from commercial fisheries for the period 1958 to 1983 was approximately 150 tonnes in Slovakia, 900 tonnes in Hungary, 1 300 tonnes in Serbia and Montenegro, 800 tonnes in Bulgaria, 2 000 tonnes in Romania and 3 000 tonnes in Ukraine (Schiemer *et al.,* 2004). Commercial fisheries in Slovakia have collapsed and now support recreational fishing only. The quality of commercial fisheries has continued to fall due to poor connectivity of the rivers and their floodplains (Schiemer *et al.,* 2004). In Bulgaria, catches have declined due to hydropower construction and water pollution, overfishing, lack of domestic demand for fishery products and a shift towards recreational fishing (Mitchell, Vanberg and Sipponen 2010). Catches of sturgeon have declined throughout the basin; previously catches yielded between 80 tonnes and 300 tonnes in Romania, Ukraine and Bulgaria, but by the 1990s the catch had declined to 25 tonnes and has continued to fall. As such, catching sturgeon is prohibited in most Danube riparian countries (Schiemer *et al.,* 2004).

Aquaculture

Aquaculture within the Danube Basin has shown signs of increasing within the last decade. In Romania, 30 aquaculture sites operate in the Danube Delta, accounting for 76 percent of the total national capacity. Common carp is the main cultured species with the largest volume of production, but other carp species (silver and bighead) are also raised. Aquaculture sites can produce 2 000 kg/ha to 3 000 kg/ha and in 2009 aquaculture production was 1 082 tonnes with a value of EUR 1.49 million (European Commission, 2009). Stocking of sturgeon species is also carried out in many Danube River countries for stock protection purposes, as wild catch of sturgeons has been prohibited for the past ten years (European Commission, 2009).

Recreational fishing

In Germany, Austria, Serbia and Slovakia, recreational fisheries are the primary component of the Danube River fisheries catches. However, data on recreational catch statistics are very scarce and data collection on recreational fishery in Europe is considered to lag behind that of Australia and the United States (EAA, 2015). It appears that with the rise in recreational fishing there are increasing incidences of conflict between commercial and recreational fishers (Smederevac-Lalić *et al.,* 2012). The value of the multispecies recreational fisheries has been badly affected by the construction of dams, consequently the quality and volume of catches have declined.

33.2 THREATS TO THE FISHERIES

Habitat modification

Navigation and hydropower construction have been described as one of the primary causes of environmental degradation in the Danube (ICPDR, 2004). In Slovakia, commercial fisheries catches collapsed after the construction of the Gabčíkovo–Nagymaros dams. Prior to construction, the mean annual catch was roughly 103 tonnes but after the dams were constructed, fish catches dropped to 27 tonnes. The commercial fishery was no longer economically viable and eventually closed (Schiemer *et al.,* 2004). Although the Gabčíkovo–Nagymaros dams were not the first infrastructure of this type to be built on the Danube, they had a considerable wide-reaching and negative impact on Danube fishing communities. Connectivity between side channels and floodplains was lost, hydrology changed and lotic systems changed to lentic ones; upstream spawning grounds were lost, which was particularly damaging for sturgeon species. As a result, both the abundance and species diversity of the Danube decreased. There have been recent efforts to restore side channel connectivity of the inland delta, but the construction of 400 new small hydropower stations in Slovakia alone will continue to threaten fish communities (Novomeská and Kováč, 2016).

Overfishing

Fisheries in the Danube Delta have been badly affected by overfishing. Stocks of bream, roach, catfish, carp, rudd and grey mullet are classed as overexploited in the Danube Delta. Most of the literature sources on overfishing within the Danube region refer to catches of sturgeon, whose populations have collapsed in all regions of the Danube. Overfishing has caused increased mortality of adult sturgeons and the size of breeding sturgeons has also decreased. Breeding sturgeons are also less likely to complete a second migration in the river and the average age of sturgeons has been declining. The heightened prevalence of poaching and increased number of fishers within the basin, using more effective gear, have increased fishing pressure during migration and spawning (Schiemer *et al.,* 2004). Water pollution and hydroelectric dam construction have also been instrumental in causing population declines in sturgeon species.

Water quality

The main influxes of nutrients into the Danube are agricultural (50 percent), municipal (25 percent) and industrial (25 percent). The total nitrogen and phosphorus load into the river is around 551 000 tonnes and 49 000 tonnes per year, respectively. The legal limit for nutrient content in groundwater is often exceeded throughout the basin; as a result the Danube is the biggest contributor of nutrients into the Black Sea (WWF, 2016). In recent years, an increasing international effort has been put into improving the water quality of the river. The TransNational Monitoring Network, a basin-wide network, found that heavy metal pollution in the lower half of the river was about 50 percent higher than that in the upper reaches. Pollution was quite low in the Austrian and Hungarian parts of the Danube, and the highest heavy metal concentrations were found at the Iron Gate Dam. High mercury pollution was identified in the Vah River (a Danube River tributary) in Slovakia, and copper and zinc contamination in other tributaries of the Austrian–Slovakian–Hungarian stretch were also found (Woitke *et al.,* 2003).

33.3 FISHERIES MANAGEMENT

Transboundary management

The European Union Water Framework Directive established in 2000, is a legal framework to protect and enhance the status of aquatic ecosystems, prevent their deterioration and ensure long-term sustainable use of water resources in the European Union (EU), to achieve 'good ecological status'. Within the framework, riverbeds and banks have to be structured, sufficient water must be ensured for migration routes and natural habitats are provided for aquatic animals. As part of the Danube River restoration of river and habitat connectivity, the status of migratory fish is a parameter of ecological conditions and an important indicator of the entire Danube River Basin. The first step was scheduled for 2019 and consisted of a feasibility study to analyse the possibility of re-opening the Iron Gate Dam for free fish migration, with an emphasis on sturgeon. If the results from this feasibility study are positive, the next steps will be to implement fish migration for the Gabčíkovo Dam (ICPDR, 2015).

Despite adoption of the Sturgeon Action Plan in 2005, measures taken at international and national levels to improve sturgeon stocks have largely failed and sturgeon populations have continued to decline. In 2012 the Danube Sturgeon Task Force aimed to improve conservation of sturgeon species to ensure viable populations of sturgeons and other indigenous species by 2020. This will be achieved through habitat protection, restoration of migration routes, supportive stocking programmes, economic alternatives to sturgeon fishery as well as combating illegal fishing and the caviar black market (DSTF, 2016).

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34 FINLAND

34.1 OVERVIEW

Freshwater lakes in Finland encompass 34 350 km^2, roughly 10 percent of the country (Table 34-1). Finland has over 56 000 lakes with a surface area exceeding 0.01 km^2 (Jurvelius and Auvinen, 2001), and 2 500 lakes with surface area of ≥ 100 km^2. The largest lake in Southeast Finland, and the fourth largest in Europe, is Lake Saimaa (4 480 km^2). The Finnish Lake District, which covers most of the central region covers an area of 116 902 km^2 and is the largest lake district in Europe (Kuusisto, 2005). These lakes are mostly oligotrophic and in a natural state. Most of the rivers in Finland flow into the Baltic Sea, or into its extensions in the Gulf of Finland (Jonsson and Jonsson, 2016). The largest river in Finland is the Kemijoki River (597 km long) with a catchment of 51 127 km^2 (HELCOM, 2011). The first hydroelectric power plant on the Kemijoki was constructed in 1948 and currently there are 17 hydropower plants on the watercourse. There are more than 200 regulated natural lakes and 30 artificial lakes larger than 1 km^2 (Lehtonen *et al.,* 2008). The water quality of Finnish rivers varies. The buffering capacity of Finnish inland waters is low and most rivers flow through boreal vegetation, where nutrient load from forestry has caused eutrophication in lakes (Jonsson and Jonsson, 2016).

Table 34-1. Inland water area and fish consumption in Finland

Inland water area (km^2)	Population of the country	Population density/km^2	Freshwater fish consumption kg/capita
34 530	5 523 230	16	15.32

Fish diversity

Most Fennoscandian species are assumed to have survived the Pleistocene glacial period south of the Nordic countries, but as the ice retreated fish species probably entered Scandinavia through the Baltic Ice Lake (later the Baltic Sea), and into Finland (Jonsson and Jonsson, 2016). At present there are 59 species recorded in Finland, of which 14 are introduced. Among the species in Finland introduced mainly for sport fishing are lake trout (*Salvenius namaycush*), brook trout (*S. fontinalis*), pink salmon (*Oncorhynchus gorbuscha*) and grass carp (*Ctenopharygodon idella*) (FishBase, 2017). Carp species and rainbow trout (*Oncorhynchus mykiss*) are common for aquaculture, particularly as rainbow trout do not easily form natural populations. Also, releases of North American largemouth bass (*Micropterus salmoides*) and smallmouth bass (*Micropterus dolomieu*) have been attempted, but none of them have been successful (Jonsson and Jonsson, 2016).

34.2 FISHERIES OVERVIEW

Fishing is an important activity in Finland. Freshwater fish are caught for human consumption and sport, but are also reared in hatcheries and fish farms for consumption. The numerous lakes and rivers offer good fishing opportunities. Commercial/professional fishing and recreational fishing activities are carried out. Commercial fishing operations are concentrated on a few species in large lakes; vendace (*Coregonus abdula*), which comprises roughly half the reported catch statistics, whitefish (*Coregonus lavaretus*), zander (*Sander lucioperca*), pike (*Esox lucius*) and perch (*Perca fluviatilis*) (Jonsson and Jonsson, 2017). Recreational fishing is hugely important in Finland with 28 percent to 40 percent of the population fishing at least once a year (Lehtonen *et al.,* 2008; OSF, 2019). Ninety percent of the inland fish catch comes from recreational fisheries, with most fish caught around highly populated areas or in the Finnish Lake District. *E. lucius* and *P. fluviatalis* are the main target species, but roach (*Rutilus rutilus*), *C. abdula*, common bream (*Abramis brama*), brown trout (*Salmo trutta*), *S. lucioperca* and burbot (*Lota lota*) are also caught in major lakes (Jonsson and Jonsson, 2016). In 2001 the recreational inland fishery was three times larger in terms of catch volume and value than the recreational sea fishery (FAO, 2005).

Fishing methods

Professional and commercial fishers mainly use gillnets, traps and other fishing gear. But the most popular fishing gear is rod and line, used by about two-thirds of fishers (Jonsson and Jonsson, 2016). Net fishing is also popular with recreational anglers accounting for 40 percent of the total recreational catch in 2017, a decline from 50 percent in 2000. The use of rod and line accounted for about 30 percent of the total recreational catch in 2017 (OSF, 2019).

Employment

The number of professional fishers in Fennoscandia has decreased over recent decades. It is estimated that there may be 1 000 professional fishers, a reduction of 50 percent over the last 20 years, of which 80 percent are Finnish (Jonsson and Jonsson, 2016). Also, according to Official Statistics of Finland (OSF), there were 1 800 registered commercial inland fishers in 2017, a substantial increase from 400 in 2014. This is attributable to regulation changes that require all commercial fishers to be registered (OSF, 2019). In 2001, the number of recreational inland fishers was four times higher than the number of recreational sea fishers (FAO, 2005). There were 1.5 million recreational anglers in 2015, a decrease from 2.0 million in 2000. Twenty-eight percent of the Finnish population is engaged in recreational fishing; demographically, 34 percent is male and 19 percent is female (OSF, 2019).

Estimated fisheries production

Estimated fisheries production in Finland from commercial and recreational catches and the FAO estimated total production are outlined in Table 34-2. The highest proportion of catch from the recreational fishery came from perch (7 640 tonnes) pike (6 700 tonnes), pikeperch (3 890 tonnes) and roach (3 100 tonnes). Most was caught in inland waters in Eastern Finland, followed by Western Finland (OSF, 2019). Between 1992 and 1996 recreational fishery landings peaked at around 60 000 tonnes and since then catches have been decreasing, as has the number of recreational fishers (FAO, 2005). The recreational fishing catch has declined by 26 percent since 2000, when the total recreational catch was 40 952 tonnes; catches in 2012 were at their lowest for 12 years (24 505 tonnes), but showed some increase in 2017 (30 000 tonnes) (OSF, 2019).

Commercial fish catches in Finland have remained largely steady since 2000, except for 2008 when catches were at their lowest (3 912 tonnes) since the 1990 to 1993 period when the average annual catch was 3 266 tonnes. The 2017 commercial fishery catches were an increase of 12 percent on catches the previous year (5 800 tonnes in 2016). Vendace has consistently comprised around 50 percent of the catches. The total value of the commercial catch in 2014 was around EUR 15.25 million and measured by value, the most important species after vendace (EUR 5.8 million) was pikeperch (EUR 4.5 million) and signal crayfish (EUR 1.1 million) (OSF, 2019).

Table 34-2. Estimated fisheries production for the inland fisheries in Finland

Fishery	Catch estimate (tonnes)	Year	Reference
Recreational	30 000	2017	OSF (2019)
Commercial/professional	6 500		
Total	**36 500**		

34.3 THREATS TO THE FISHERIES

Habitat modification

Loss of habitat is one of the primary threats to freshwater fish production in the Nordic countries (Jonsson and Jonsson, 2016). River regulation for hydropower has affected fisheries negatively, but the specific impacts of dams on fisheries in Finland are not known. Dams and weirs can delay the migration of anadromous fishes (Svendsen, Koed and Aarestrup 2004). Accumulation of *S. trutta* downstream of weirs is well known (Linnik *et al.,* 1998). Weirs also increase the vulnerability of migratory fish to anglers and alter natural migration patterns; overcrowding of fish at downstream pools can facilitate the spread of disease (Jonsson and Jonsson, 2017). The dredging of streams in Finland to facilitate log transportation was the one of the aims of river channelization (Jutila, 1992). By the 1950s, 13 000 km of streams had been dredged for log transport. This resulted in the creation of homogenous stream channels with simplified flows that lowered the river bed. Such activities have changed the diversity of river habitats and led to fishery reductions (Lehtonen *et al.,* 2008). Deforestation and agricultural land use have caused degradation of aquatic environments in Finland. Increased forestry activities have caused more nutrient loading into rivers and lakes that has caused eutrophication in some small lakes. Also, draining of forests and wetlands has affected the hydrology of catchments and increased erosion has generated river sedimentation (Jurvelius and Auvinen, 2001).

Water quality

Surface water acidification from long-range sulphur transportation has led to the decline in fisheries in Finland. In 1995, 10 percent of lakes in Finland had sulphur acidity levels over the estimated critical load (Henriksen *et al.,* 1998). In Finland, acidification affected the abundance of 2 200 to 4 400 fish populations and 1 000 to 2 000 fish populations became extinct (Rask *et al.,* 1995). Almost 60 percent of the affected or lost populations was *R. rutilus*, but *P. fluviatilis, E. lucius* and *L. lota* were also devastated (Jonsson and Jonsson, 2016).

Climate change

Temperature increases in Finland by approximately 1 °C have been observed since the nineteenth century. However, climate projections predict the annual mean temperature to increase 3 °C to 6 °C by the end of this century, with a greater increase in winter months. Precipitation levels are predicted to increase 10 percent to 25 percent by the end of the century, with greater rainfall and less snowfall. Changes in yearly runoff are estimated at -5 percent and +10 percent depending on the catchment area. Increasing temperature and runoff and the resultant changes to nutrient loads may have profound impacts on aquatic ecosystems. Some characteristic Finnish species, such as cold-water species, may become extinct, even if climate change will most likely increase flora and fauna in Finland (OECD, 2013). For instance, it is assumed that the climate currently restricts the northerly distribution of some species such as *E. lucius, R. rutilus*, tench (*Tinca tinca*) and *L. idus*, but it is expected that their range will move northwards as the climate warms (Jonsson and Jonsson, 2011). This has already been observed as *E. lucius, R. rutilus* and *L. idus* have become more abundant in the delta and the Sredinnaya Guba Estuary on the Barents Sea (Reist *et al.,* 2006).

34.4 EQUIVALENT FOOD REPLACEMENT

Freshwater fisheries in Finland are mainly recreational and far exceed the commercial fishery inland catch. Per capita freshwater fish consumption in Finland is some of the highest in world (15.32 kg/capita/year) and consequently the loss of inland fisheries would be detrimental to the population. But as a developed country, the impact on food security would be minimal as other sources of food could easily be sourced, although they might not be preferred over fish. There would, however, be severe economic and social impacts on populations from the loss of capture fisheries. Equivalent food replacement estimates were established for the replacement of the total estimated fisheries production and FAO estimated fisheries production (Table 34-2) to provide a range of the possible impacts on food production, water use and land use. Replacement food sources are farmed salmon and rainbow trout, beef, pork, chicken and wheat.

Table 34-3. Food production (tonnes), water (million m³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (thousand tonnes)
Salmon	19 829 (825.9)	44.8 (89.6)		17.73
Rainbow trout	27 868 (1313.9)	122.1 (244.1)		21.17
Beef	22 662 (26.3)	349.3 (698.7)	1 920 (581.9)	1 418.81
Pork	11 852 (6.5)	70.9 (141.9)	1 616 (489.8)	6.56
Chicken	37 325 (30.9)	161.4 (322.9)	1 675 (507.6)	88.41
Wheat	57 205 (7.1)	104.5 (209.0)	172 (0.1)	1.87

Energy replacement (Table 34-3)

Replacement of capture fisheries (36 500 tonnes) would require an increase in food production. Farmed salmon production would require an increase equivalent to 8.2 times of current farmed salmon production (2016 farmed salmon production was 2 401 tonnes). Replacement of capture fisheries with rainbow trout would require an increase equivalent to 13 times of current production (2 121 tonnes in 2016). Beef production would have to increase by 22 662 tonnes to replace kilojoules from fisheries, equivalent to 26.3 percent of current beef production (2017 beef production was 86 080 tonnes). Wheat production would require the largest production increase to replace capture fisheries, equivalent to 7.1 percent of wheat production in 2014 (wheat production was 0.8 million tonnes in 2017).

Water demand (Table 34-3)

Replacement beef production would require the largest increase in water use, equivalent to 7.0 times the current agricultural water use (agricultural water use was $5.00{\times}10^{7}$ m³). Replacement chicken production would require three times the current agricultural water use. Replacement rainbow trout production would be equivalent to 2.4 times of agricultural water use. Replacement pork production would require 70.9 million m³ of water to replace fisheries, equivalent to a 1.4 times increase in current agricultural water use. Replacement farmed salmon production would require the lowest water replacement, equivalent to 89.6 percent of agricultural water use in Finland.

Land requirements (Table 34-3)

Replacement beef production would require the largest land conversion, equivalent to 582 percent of the current pastureland in (2016 pastureland area was 330 km²). Pork production would require the smallest land conversion, equivalent to 489.8 percent of the pastureland in Finland. Conversely, replacement wheat production would require 172 km² of land to replace fisheries, equivalent to 0.1 percent of agricultural land in Finland (2016 agricultural land area was 226 710 km²).

Greenhouse gas emissions (Table 34-3)

Estimated carbon emissions from capture fisheries in Finland were 110 231 to 130 039 tonnes. Replacement of fisheries in Finland would result in a net increase in carbon emissions, which would be highest for beef replacement (1.4 million tonnes). Other replacement food would result in a net increase of 88 409 tonnes for chicken, 21 174 tonnes for rainbow trout, 17 723 tonnes for farmed salmon, 6 555 tonnes for pork and 1 875 tonnes for wheat.

34.5 FISHERIES MANAGEMENT

Inland fisheries in Finland are governed under the Finnish Fisheries Act, 1982, which targets maximum sustainable productivity from water areas used for fishing. This goal integrates fisheries management into the wider context of sustainable use of renewable resources. As part of the Fisheries Act, fisheries management units were set up to represent an intermediate level of public administration that has duties such as preparing management plans and fishing regulations.

Regional government fisheries administration was also established under the Ministry of Agriculture and Forestry in 1983, which implements the Fisheries Act, mainly by looking after fishery interests and allocating public subsidies (Sipponen, 2001).

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35 MAGDALENA RIVER

35.1 OVERVIEW

The Magdalena River covers 24 percent of the territorial area in Colombia (Table 35-1). The source of the river is 3 800 m above sea level in the southern Colombian Andes and flows parallel to the Cordilleras Mountain Range for 1 540 km to its mouth on the Caribbean Sea. The Magdalena River also drains three tributaries: the Cauca, Sogamoso and San Jorge rivers. The river's topography comprises the Upper Magdalena Valley (a fast-flowing section of river), the Middle Magdalena Valley (wider and slower flowing and where the Sogamoso confluence meets the Magdalena) and the Lower Magdalena Valley (from the Sogamoso confluence into the Mompos Depression) (Galvis and Mojica, 2007). At the mouth of the river, the average discharge is 7 100 m^3/s. The lower part of the basin forms an extensive floodplain with many lagoons and marshes covering an estimated area of 22 000 km^2. The Magdalena River supports the largest fishery in Colombia and is densely populated by 80 percent of Colombia's population (Galvis and Mojica, 2007).

Table 35-1. Characteristics of the Magdalena River Basin

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
Colombia	259 590	99.98	31 964 055	123
Venezuela	41	0.02	707	17
Total	**259 631**	**100**	**31 964 762**	**70**

Fish diversity

According to FishBase there are 136 species and five endemic species in the Magdalena River Basin. Most are from the families Characidae (35 species) and Loricariidae (20 species). There are also five endemic species – *Abramites eques, Panaque cochliodon, Megalonema xanthum, Cynodonichthys boehlkei* and *C. magdalenae* (FishBase, 2017). However, Barletta *et al.* (2016) asserted that ichthyofauna in the Magdalena River comprised 213 species, corresponding to 15 percent of all known fish in Colombian rivers and described the basin as having high endemism (more than 55 percent). Nineteen freshwater fish species from the Magdalena River are included in the *Red book of freshwater fishes of Colombia*. Two are important in fisheries and are classed as critically endangered (*Prochilodus magdalenae* and *Pseudoplatystoma fasciatum*), three are endangered (*Ageneiosus pardalis, Ichthyoelephas longirostris* and *Sorubim cuspicaudus*), eight are vulnerable and six are near threatened (Mojica, 2002).

Fish introductions

There have been three documented fish introductions according FishBase – Nile tilapia (*Oreochromis niloticus*), snakeskin gourami (*Trichopodus pectoralis*) and pacu (*Colossoma macropomum*) (FishBase, 2017). This contrasts with Barletta *et al.* (2016) and Gutiérrez *et al.* (2013) who stated that at least 29 fish species have been introduced (including *Oncorhynchus* spp., *Tilapia* spp. and *Oreochromis* spp.) or transplanted (*Arapaima gigas*, *Cichla ocellaris, Colossoma macropomum* and *Piaractus brachypomum*) into the Magdalena River Basin as compensation for native fisheries depletion.

35.2 FISHERIES OVERVIEW

The Magdalena River supports the largest freshwater fishery in Colombia, representing about 55 percent of fisheries production, exceeding the Orinoco and Amazon rivers (Barletta *et al.,* 2016). The small-scale fisheries of the Magdalena River Basin are based on many species and catches mainly consist of Prochilodontidae and Pimelodidae caught by both part-time and full-time fishers (Barletta *et al.,* 2016). Most of the mountain species are small and lack commercial importance, but some are consumed locally. The main species that contribute towards fisheries within the basin are bocachico (*Prochilodus*

magdalenae), bagre rayado (*Pseudoplatystoma magdaleniatum*), blanquillo (*Sorubim cuspicaudus*) and barbudo (*Pimelodus blochii*). In the Upper Magdalena Valley, the main catches are based on *Pimelodus clarias, Prochilodus magdalenae, Ichthyoelephas longirostris* and *Pseudoplatystoma fasciatum* (Galvia and Mojica, 2007). Because of the flooding regime the river experiences, fisheries in the Magdalena River have two periods with high yields that correspond with fish migration from the floodplain lakes to the main river. The main fish migration known as *subienda* occurs between December and March, the second migration between July and August is known as *mitaca* (Barletta *et al.,* 2016).
Thirteen per cent

Fishing methods

The Magdalena River fisheries use multiple types of gear. The Colombian Fisheries Statistical Service (SEPEC) stated that in 2015, seven types were used to catch freshwater fish species in the Magdalena River – cast nets, seine nets, handlines, longlines, gillnets, drift nets and fish traps. The use of gillnets accounted for 29 percent of the fish catch followed by seine nets (18 percent), cast nets (8 percent) and drift nets (6.3 percent) (SEPEC, 2017).

Fish trade

The fisheries yield in the Magdalena River is mainly destined for consumption within the country. In 2013, the monetary value of the Magdalena River fisheries (4 130 tonnes) for the January to August period of 2013 was COP 17.9 million representing 73 percent of the total value of inland fishery yield in Colombia and 41.5 percent of the total fishery value in Colombia, second only to the country's Pacific marine fishery (43 percent) (SEPEC, 2014).

Employment

Currently SEPEC does not collect data concerning employment in fisheries. The only estimates available are those from literature sources. The Upper Magdalena Valley is considered a more prosperous part of the country, where fishing is a seasonal activity carried out by part-time fishers during the *subienda* migration; fishing juxtaposes other jobs such as those in agriculture. In the Middle Magdalena Valley, there are some 8 000 fishers; overall the Magdalena River supports 35 000 fishers (Mojica, 2002).

Estimated fisheries production

Estimated freshwater capture fisheries production from the Magdalena River Basin is outlined in Table 35-2. There were no figures available for the Venezuelan portion of the basin, but this is expected to be small given its size and high elevation in the Andes where there is minimal capture production. The capture fishery value for the Magdalena Basin in Table 35-2 represents 83 percent of freshwater fisheries production from major rivers in Colombia in 2013 (Amazon, 1 028 tonnes and Orinoco, 155 tonnes). Fisheries data for 2014 to 2016 were available for the Magdalena River, but the figure in Table 35-2 is from the most recent year that data had been recorded continuously throughout the year. In 2015 data were gathered from April to December with the remaining data collected via reconstruction and information retrieval. In 2014, data were only collected from January to mid-June and again from November to December with no data collection in the intervening months. In 2016 data were only collected between July and December with no data collection in the previous months. Such variation in data collection does not allow accurate assessment of the state of fishery resources, which are considered to be declining in the Magdalena River Basin.

Table 35-2. Estimates fisheries production in the Magdalena River

Country	Catch estimate (tonnes)	Year	Reference
Colombia	5 808	2013	SEPEC (2017)

Status of the fisheries: catch trends

Fisheries within the Magdalena River Basin have had an accelerated reduction in catches and a progressive change in composition of species, including lower quality species previously not harvested. Historically, the fishery concentrated on larger fishes such as *Pseudoplatystoma fasciatum* and *Tarpon atlanticus,* but a drastic increase in human population after the 1960s led to a change in catch composition to detritivorous species (e.g. *Prochilodus magdalenae*) that made up 60 percent of the catches (Mojica, 2002). Once the stocks of commercial fish species began to decline fishers started to catch fish of increasing smaller size and lower quality such as *Cyphocharax magdalenae, Centrochir crocodilii* and *Hoplosternum magdalenae* (Mojica, 2002). Initial estimates of fishery production in the early 1970s suggested annual fish yield of around 60 000 tonnes/year to 80 000 tonnes/year. Fish catches in the 1990s dropped to below 10 000 tonnes/year from 1995 to 1998 owing to a drought caused by an El Niño event. Fisheries showed some signs of recovery in the early 2000s climbing to around 15 000 tonnes (Galvis and Mojica, 2007), but catches have since declined and have levelled out at around 6 000 tonnes/year (SEPEC, 2017). The fisheries catch in 2013 showed a 36 percent decrease compared to 2004 (9 094 tonnes) (FAO, 2015).

Aquaculture

Fish farming was introduced to the Magdalena River basin as compensation for fisheries depletion. Aquaculture involves the use of native and introduced species such as black cachama (*Colossoma macropomum*), tilapia (*Oreochromis* spp. and *Oreochromis niloticus*), common carp (*Cyprinus carpio*), bagre rayado (*Pseudoplatystoma magdalentium*), bocachico (*Prochilodus magdalenae*), white cachama (*Piaractus brachypomus*) and Sábalo (*Brycon amazonicus*). The main aquaculture activities are carried out in the municipalities of Tolima and Hulia within the Magdalena River Basin. Production in 2016 was around 500 000 tonnes, a considerable increase from 42 000 tonnes in the 1990s (SEPEC, 2017).

Recreational fishing

There are five recognized sport fishing events that take place every year on the main tributary of the Magdalena and the Cauca River, however, the catch and participation in this fishery is unknown (FAO, 2003).

35.3 THREATS TO THE FISHERIES

Habitat modification

Expansion in agriculture and cattle ranching led to radical changes in the environmental conditions of the Magdalena River Basin during the twentieth century. Between 1950 and 1980, nearly 40 000 km^2 of rain forest in the Middle Magdalena Valley were destroyed to accommodate government-promoted agricultural expansion (Galvis and Mojica, 2007). This led to a loss of nursery habitats and a large increase in sedimentation that clogged channels and lagoons in the lower valleys (Barletta *et al.,* 2016). The rate of deforestation in the basin has been 1.9 percent/year (Restrepo and Restrepo, 2005), the highest in South America (Tucker and Townsend, 2000) and more than 55 percent of the forest within the Magdalena Basin has been destroyed for agricultural expansion (CORMAGDALEN-IDEAM, 2001). Also, in the lower floodplains, landowners have drained 1 000 km^2 of the floodplain area, and another 2 000 km^2 are being drained as part of a sustainable agriculture programme for the Mojana region (DNP-FAO, 2003). Currently the Magdalena River has two dams, the Betania Dam and the Quimbo Dam, which have had fairly localized impacts on habitat loss as they are built above the upper limits of fish migration (Galvis and Mojica, 2007). But a master plan agreement between Colombia and China for the development of the Magdalena River could see the construction of 11 to 15 more dams within the basin. The exact impact of these dams on fish and fisheries has not been tested, but future dams would have a major negative impact basin-wide (International Rivers, 2017).

Water quality

As the centre for agricultural and industrial development in Colombia, the Magdalena River Basin has experienced an increase in levels of organic, heavy metal and agricultural pollution. The basin produces 93 percent and 90 percent of non-metallic minerals in Colombia (DANE, 2004). Gold mining within the basin has been responsible for the introduction of many pollutants into the river, such as mercury, cyanide, lead, zinc and copper (Barletta *et al.,* 2016). Indeed, the Mundial Health Organisation found that mercury accumulation in fish from rivers draining mining areas was above the accepted concentration for human consumption (DNP-FAO, 2003). This has led to health problems among fishers and their families (Olivero, Johnson and Arguello, 2002). Furthermore, the principal source of pollution in the Magdalena Basin is untreated sewage from the main cities of Bogotá, Calí and Medellín but the impact on fish in the basin has not been evaluated (Galvis and Mojica, 2007).

Overexploitation

The increase in demand for fish products and human population density in the Magdalena River Basin is the highest in South America (123 individuals/km^2) (DANE, 2005). Given that freshwater fish consumption in Colombia was 3.14 kg/capita/year in 2013, the catch from the Magdalena River does not satisfy demand. The basin has approximately 35 000 fishers, which is too many, but fishers and their families lack other livelihood opportunities. During the *subienda* migration, fishing intensity is at its greatest and roughly 60 percent of the total basin catch is harvested during this time (Valderrama *et al.,* 1993). Also, fish sampling has indicated that many commercial species in the Magdalena River are harvested before they reach maturity, contributing to the depletion of fish resources. It is estimated that 71 percent of harvested *P. magdalenae* is not mature, as well as 96 percent of *Pimelodus grosskopfii*, 58 percent of *Sorubim cuspicaudus*, 83 percent of *P. blochii*, 82 percent of *Caquetaia kraussii* and 83 percent of *Pseudoplatystoma magdaleniatum* (AUNP, 2013).

Climate change

Specific implications of climate change on fisheries within the Magdalena River Basin are not known. But temperature increases across Colombia are predicted to increase 1 °C to 2.5 °C by 2100. The Magdalena River Basin shows high vulnerability to flooding, with an increase in the intensity and occurrence of floods, and sea-level rise of 40 cm to 60 cm. Fisheries depletion in the Magdalena has also been attributed to the consequences of El Niño/La Niña events (Jiménez-Segura, 2007), for which correspondence between fisheries catches and El Niño cycles have been inferred but not tested (GFDRR, 2011).

35.4 EQUIVALENT FOOD REPLACEMENT

The Magdalena River represented more than 80 percent of the inland capture fisheries production in 2013; there was a large fisher population that depended on fishing for their livelihoods. Food replacement estimates were established for a 50 percent loss to fisheries production and are outlined in Table 35-2 (Venezuela is not included in any analysis as there were no catch data for the Venezuelan portion of the Magdalena given its small area). Food replacement items consist of livestock (beef, pork and chicken), aquaculture (cachama [pacu], tilapia and common carp) and cassava.

Table 35-3. Food production (tonnes), water (million m³), land (km²) and net increase in carbon emissions (thousand tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (thousand tonnes)
Cachama	1 823 (115.5)	6.25 (0.1)	28 (0.01)	
Tilapia	1 718 (2.8)	5.1 (0.08)	78 (0.03)	0.45
Common carp	1 754 (295.9)	5.5 (0.09)	292 (0.09)	
Beef	1 803 (0.2)	27.8 (0.4)	208 (0.05)	112.90
Pork	943 (0.4)	5.6 (0.09)	128 (0.03)	0.52
Chicken	2 969 (0.2)	12.8 (0.2)	80 (0.02)	7.03
Cassava	2 154 (0.1)	3.9 (0.06)	2 (0.01)	

Energy replacement (Table 35-3)

Aquaculture practices would need to increase to replace capture fisheries in the Magdalena River. Farmed cachama production would require the equivalent of 115 percent of current production (production in 2015 was 1 579 tonnes). Farmed common carp would require the equivalent of 296 percent of current production (production in 2015 was 593 tonnes). Chicken and cassava production would require the largest increase; however, current production of chicken and cassava is high so this value is low in terms of current production (0.2 percent and 0.1 percent of current production, which was 1.3 million tonnes and 2.2 million tonnes respectively in 2018).

Water demand (Table 35-3)

Beef production would have the largest impact on freshwater resources in the Magdalena River Basin, equivalent to 0.4 percent of agricultural water withdrawals from Colombia (6.9 km³ in 2008). Water demand from chicken production is roughly half that of beef production and is equivalent to 0.2 percent of agricultural water withdrawals. Aquaculture and pork production would require similar water demands, equivalent to 0.08 percent to 0.1 percent of agricultural water withdrawals from Colombia.

Land requirements (Table 35-3)

Farmed common carp would require the largest land conversions, equivalent to 0.09 percent of the Magdalena River Basin. Beef production would require the largest land conversion from a terrestrial food source, equivalent to 0.05 percent of the pastureland area in Colombia (pastureland area was 413 649 km² in 2014).

Greenhouse gas emissions (Table 35-3)

Carbon emissions from 50 percent of capture fisheries production in the Magdalena River were estimated at 10 919.5 tonnes. Net increases in carbon emissions from replacement of fisheries with alternative food sources would be highest for beef production (112 887 tonnes), followed by chicken (7 034 tonnes), pork (521 tonnes) and farmed tilapia (447 tonnes).

35.5 FISHERIES MANAGEMENT

The National Authority for Aquaculture and Fisheries is the main governmental body in charge of fisheries and aquaculture management. Other governmental bodies that have management input in fisheries regulations in Colombia are the Executive Committee for Fisheries, the Ministry of Agriculture and Rural Development and the Ministry of Environment and Sustainable Development, each of which is responsible for different areas of management. Fragmentation of fisheries management and governance has led to management inconsistencies, and poor implementation of regulations has weakened management. Managing fisheries in Colombia is considered particularly difficult due to the geographical and social context of Colombia, a country with many diverse watersheds and ecosystems.

Fisheries in Colombia are currently managed by individual species, through regulated open access regimes that restrict areas and seasons where fishing is permitted. Fishing licences are also required to carry out fishing activities. The Colombian Government has recognized that the existing management framework is inadequate and outdated and does not promote the sustainable management of Colombian fisheries. Currently a reform of the institutional and legal framework for fisheries is underway and two draft laws have been designed by the government but will not come into force until 2018. The draft laws aim to regulate the sustainable exploitation of fisheries resources and assist the development of aquaculture, and also establish measures against illegal fishing and illegal fishing activities (OECD, 2016).

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36 ORINOCO RIVER

36.1 OVERVIEW

The Orinoco River is one of the largest rivers in South America and encompasses 84 percent of Venezuela's territory with a small portion flowing through Colombia (Table 36-1). It is the third largest river by discharge (38 000 m^3/s) after the Amazon and the Congo. The river flows for 2 410 km from the headwaters in the Andes to the Atlantic Ocean (Rodríguez *et al.,* 2007). The river is bound on its southern margin by the Rio Negro. The river has four sections: the Upper Orinoco, Middle Orinoco, Lower Orinoco and the Orinoco Delta, where the mainstream branches into hundreds of smaller rivers and forms an extensive floodplain of approximately 21 000 km^2. The Orinoco River has 11 major tributaries, the largest of which are the Caroní and Apure rivers in Venezuela, as well as the Casiquaire Canal, a tributary that flows into the Rio Negro. The climate of the Orinoco Basin is mainly tropical and the southern part of the basin receives high precipitation (1 000 mm/year to 4 000 mm/year), whereas the northern areas are semi-arid (Rodríguez *et al.,* 2007).

Table 36-1. Characteristics of the Orinoco River

Country	Area of the river (km^2)	Percent area of river in countries	Population of the river basin	Population density/km^2
Venezuela	626 836	84	8 524 217	145
Colombia	346 185	16	4 287 412	12
Total	**973 023**	**100**	**12 811 630**	**79**

Fish diversity

Aquatic habitats in the Orinoco River vary greatly but habitat for fish in the main channel is limited. If found at all, fish use the mainstream for dispersal between backwaters and tributaries. FishBase reports 593 species from the Orinoco Basin, of which 11 species are endemic; most species are from the Characidae (95 species) and Loricariidae (61 species) families (FishBase, 2016). The largest aquatic fauna and flora are found on the Orinoco floodplains (Lewis *et al.,* 2001) and published literature lists some 1 200 species of freshwater fish (Lasso *et al.,* 2004). Species richness in the Orinoco Delta accounts for 315 freshwater species from 11 Orders, or 450 if estuarine species are included (Petry and Hales, 2013). The Orinoco River is habitat to some iconic species such as the critically endangered Orinoco crocodile, river dolphins, giant river otters and the giant anaconda (WWF, 2017).

Fish introductions

According to FishBase the only documented introduced species is snakeskin gourami (*Trichopodus pectoralis*) (FishBase, 2016). However according to the literature, cultivated tilapia (*Oreochromis* spp.) has escaped into the wild (Rodríguez *et al.,* 2007).

36.2 FISHERIES OVERVIEW

The aquatic habitat of the Orinoco Basin supports commercial, sport and subsistence fisheries. The largest fishery in the region is in Venezuela, centred at San Fernando de Apure. The Orinoco River fishery is a multispecies fishery, with approximately 80 species commonly found in the fish markets. Most of the catch consists of prochilodontids and pimelodid catfish (Rodríguez *et al.,* 2007). Novoa (1989) reported that commercial fishery catches within the basin expanded during the 1980s through a shift in catches of large pimelodid catfish to a greater reliance on migratory prochilodontids. Fish species that make up commercial fisheries include the commonly known coporo (*Prochilodus mariae*) and bagres, which dominate fisheries in San Fernando. However, morocoto (*Piaractus brachypomus*) and cachama (*Colossoma macropomus*) are also important commercial species (Rodríguez *et al.,* 2007). Although fishing is conducted all year round, there is marked seasonality with the highest abundance of fish captured occurring between November and April during the dry season, when fish are isolated in smaller pools and are easier to catch (FAO, 2005).

Fishing methods

In the Venezuelan portion of the Orinoco River fishing is mainly conducted with gillnets and seine nets. In some areas, especially during the annual floods and upstream migrations, cast nets, known as *chinchorro*, are also used. Additionally, hooks mounted on hand lines, longlines and bottom spinners are used to catch large catfish. In the Apure River, the most common types of fishing gear are trammel nets, gillnets, hooks, seine and cast nets (Barletta *et al.,* 2016). Indigenous communities use spears and bow and arrow to catch fish (FAO, 2005).

Fish trade

Trade statistics are not considered reliable for the region as an unknown and probably substantial proportion of all exports is traded illegally through Colombia and the Amazonas region of Brazil. There is no serious trade of ornamental fish in Venezuela or Colombia. The major fish markets are located in Puerto Ayacucho, Guasdualito, Bruzual, Caicara del Orinoco, Maripa, Ciudad Bolívar, Ciudad Guayana and Barrancas (Rodríguez *et al.,* 2007).

Employment

Table 36-2 indicates participation in Orinoco River Basin fisheries by Colombia and Venezuela. It is estimated that 2 500 people are employed in the primary fishing sector in Colombia (Barletta *et al.,* 2016), although the demographics for secondary activities are not known. In Venezuela, there are no current data on the number of fishing licences, and there is no official registry on the number of fishers. Data from FAO for the region indicated that 650 boats were in operation, assuming each boat was managed by three to four people; Barletta *et al.* (2016) estimated that between 2 500 to 3 000 people were directly involved in fishing activities in the major market towns of Bolívar and Cabruta. In the Apure River, FAO recorded 3 285 fishing boats in operation, which suggests that around 12 000 fishers exploit fisheries in this region (Barletta *et al.,* 2016). Employment figures for Venezuela are considered approximate, as these data only account for commercial fishers and exclude the many fishers in remote areas who fish for subsistence purposes and are not registered. For instance, in the Lower Orinoco Delta it is estimated that there are 1 000 to 1 500 indigenous fishers belonging to the Warao ethnic group (FAO, 2005).

Table 36-2. Participation in Orinoco River Basin fisheries activities

Country	Fishers
Colombia	2 500
Venezuela	15 000
Total	**17 500**

Source: Barletta *et al.* (2016).

Estimated fisheries production

Table 36-3 indicates the estimated fisheries production from literature sources for the Orinoco River. In the Colombian Orinoco Basin, CPUE varies among the various tributaries of the Orinoco River from 5.7 kg to 60 kg/canoe/day (Barletta *et al.,* 2016). Fisheries in Colombia show marked seasonality, with highest volumes of catch coinciding with decreasing and low water levels (Barletta *et al.,* 2016).

In Venezuela, inland fisheries are concentrated in the Orinoco Basin and fishery yields are correlated with the intensity of seasonal floods (Rodríguez *et al.,* 2007). Fisheries estimates for the Venezuelan Orinoco Basin are varied and Novoa (1989) previously estimated an annual yield of 40 000 tonnes to 45 000 tonnes for the Orinoco River; multispecies fishery yields were estimated at 12 000 tonnes in the mid-1980s. Conversely, a food web analysis conducted by Lewis *et al.* (2001) estimated 79 000 tonnes for the Orinoco floodplain alone.

Table 36-3. Production estimates for the Orinoco River Basin

Country/river		Catch estimate (tonnes)	Year	Reference
Venezuela	Orinoco	60 000	1995	Novoa (2002)
	Apure	30 000	2008	Machado-Allison and Bottini (2009)
Colombia		1 024	2009	Ramírez-Gill and Ajaco-Martínez (2011)
Total		**91 024**		

Status of the fisheries: catch trends

For Colombia, 1995 to 2009 records indicated that fish catches decreased from 7 742 tonnes to 1 024 tonnes (Ramírez-Gill and Ajaco-Martínez, 2011). In Venezuela, INSOPESCA, the Venezuelan national fishery agency, reported annual harvests of 16 000 tonnes to 60 000 tonnes between 1984 and 2000, which represented 3 percent to 12 percent of the country's fishery production (Novoa, 2002). Records for the Apure River indicated that catches had declined from 60 000 tonnes to 30 000 tonnes from 1996 to 2008 (INSOPESCA, 2009).

Aquaculture

Fish farming is relatively underdeveloped in Venezuela, partly due to lack of funding. Aquaculture within the Orinoco River Basin mainly focuses on cachama (*C. macropomum*), which dominates production, but culture of exotic tilapia (*Oreochromis* and *Sarotherodon* spp.) is becoming more common. Most fish-farming activities use earthen ponds to cultivate cachama but the use of cage culture has provided positive results experimentally. Commercial ventures in aquaculture are hindered by the unavailability of high-quality fingerlings and the absence of adequate advice and guidance on fish culture (Rodríguez *et al.,* 2007).

Recreational fisheries

In Colombia, sport fishing is only allowed during the dry season (November to April). The River Bita, a tributary of the Orinoco River, is a popular site for sport anglers and the most common sport fish is the pavón, or peacock cichlid (Gómez and Jorgensen, 1999).

Similarly, in Venezuela the most important sport fish is the pavón, but other popular sport fish include the payara (*Hydrolycus armatus*), migratory characids and large pimelodid catfish including the bagres rayados (*Pseudoplatystoma fasciatum*), valentón (*Brachyplatystoma filamentosum*) and cajaro (*Phractocephalus hemioliopterus*) (Rodríguez *et al.,* 2007).

36.3 THREATS TO THE FISHERIES

Overexploitation and overfishing

Despite an increase in fishing effort, the number of boats, fishers and improvements in fishing technology, catches have continued to decline (Barletta *et al.,* 2016). The use of nylon seine nets has contributed to the decline of stocks of large catfish and declining mesh sizes in the commercial fishery are indicative of reductions in larger individuals, average size and age at maturity (Rodríguez *et al.,* 2007). Catches of commercial species have declined; catfish (*Pseudoplatystoma orinocense* and *P. tigrinum*) catches diminished from 8 815 tonnes to 2 782 tonnes from 1996 to 2015. The same situation applies for the flatwhiskered catfish (*Pinirampus pinirampus*), which declined from 2 562 tonnes to 1 297 tonnes, gilded catfish (from 1 384 tonnes to 61 tonnes), pacu (from 2 062 tonnes to 460 tonnes), *P. mariae* (from 17 918 tonnes to 8 473 tonnes), *M. duriventre* (from 2 490 tonnes to 1 730 tonnes) and red-bellied pacu (*Colossoma macropomum*) (from 1 254 tonnes to 951 tonnes) (Barletta *et al.,* 2016).

Habitat degradation

Deforestation has had the most widespread and far-reaching impact on aquatic life within the Orinoco Basin. Land clearing in the Upper Orinoco has resulted in erosion and siltation of streams and rivers, greater solar radiation, stream desiccation and alteration of instream habitats (Rodríguez *et al.,* 2007). For example, *C. macropomum* is protected during its breeding season, however, there has been no recovery in its population. It is possible that degradation of the riparian habitat and deforestation has contributed to the decline of *C. macropomum,* as habitat degradation has led to the destruction of its food sources (Barletta *et al.,* 2016).

36.4 EQUIVALENT FOOD REPLACEMENT

Freshwater fish of the Orinoco River are observed to be declining and anthropogenic stressors such as habitat degradation and overfishing are having a compounded impact on aquatic resources within the basin. Replacement of capture fisheries was based on a 100 percent loss to capture fisheries production (from the total basin production in Table 36-3). Equivalent replacement estimates from other livestock (beef, pork and chicken), crops (cassava and maize) and aquaculture products (pacu and tilapia) were established (Table 36-4).

Table 36-4. Food production (tonnes), water (million m³), land (km²) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/ pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Pacu	57 142 (3103)	0.2 (0.8)	857 (0.09)	
Tilapia	53 851 (93.4))	0.2 (0.7)	2 447 (0.3)	0.01
Beef	56 514 (4.15)	0.9 (3.8)	6 520 (3.3)	3.54
Pork	29 556 (6.4)	0.2 (0.8)	4 030 (2.1)	0.02
Chicken	93 083 (4.1)	0.4 (1.7)	2 497 (1.3)	0.22
Maize	119 601(2.7)	0.2 (0.6)	213 (0.5)	0.005
Cassava	67 535 (3.1)	0.1 (0.5)	60 (0.2)	

Energy replacement (Table 36-4)

Aquaculture is not well developed in Venezuela or Colombia, hence in terms of current production levels, replacement of capture fisheries would require a significant increase in current production. Pacu aquaculture would require equivalence to 31 times current production (production in 2015 was 1 841 tonnes). Similarly, tilapia production is low and replacement would be equivalent to 93 percent of current farmed tilapia production (2015 production was 61 093 tonnes).

Water demand (Table 36-4)

Beef as a replacement source would have the largest impact on freshwater resources in the Orinoco Basin, equivalent to 3.8 percent of current agricultural water withdrawals from Venezuela and Colombia (agricultural water use was 23.1 km³ in 2016). Chicken production would require 0.4 km³, equivalent to 1.7 percent of agricultural water withdrawals from Venezuela and Colombia.

Land requirements (Table 36-4)

Beef replacement requires the largest land conversion, equivalent to 3.3 percent of the pastureland area in Venezuela and Bolivia (2014 pastureland area was 198 752 km²). Maize and cassava would require

213 km^2 and 60 km^2 respectively to replace fisheries, equivalent to 0.5 percent and 0.2 percent of arable land in use within the basin countries (arable land area in the riparian states was 43 752 km^2 in 2018).

Greenhouse gas emissions (Table 36-4)

Estimated greenhouse gas emissions from capture fisheries of the Orinoco River were estimated at 342 250 tonnes. Replacement of capture fisheries with equivalent food sources would lead to a net increase in carbon emissions of 3.54 million tonnes from beef production, 0.22 million tonnes from chicken production and 0.01 million tonnes to 0.02 million tonnes from replacement with tilapia and pork, respectively.

36.5 FISHERIES MANAGEMENT

National management strategies

The Ministry of Agriculture is responsible for the management of fisheries in Venezuela. Issuing of fish licences and permits is governed in legislation, but these laws are not enforced, and law enforcement bodies only make occasional arrests or confiscate fishing gear – too few and far between to create an environment of compliance. Rural fishers, who account for approximately 70 percent of fishery harvests, are effectively ignored by the state, where commercial fisheries are perceived as a priority. This has led to conflict between rural and commercial fishers (Rodríguez *et al.,* 2007).

There is some degree of protection of fisheries through a network of protected areas, which cover two-thirds of Venezuela's territory; these include faunal refuges and reserves that are concentrated in the southern part of the Orinoco Basin. Pacu are protected during their breeding season. Closed seasons are implemented for catfish which showed catch recovery in 2009 similar to levels in 1980s. However, protection of ecologically vulnerable areas is lacking as they are not actively managed or monitored, and the main focus of fisheries managers is on fish harvesting rather than protecting fisheries sustainability (Rodríguez *et al.,* 2007).

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37 AMAZON RIVER

37.1 OVERVIEW

The Amazon River runs for approximately 7 100 km from its source in Peru to the Atlantic Ocean and is the world's longest, widest and deepest river (Table 37-1). Its discharge of 210 000 tonnes to 219 000 m^3/s exceeds the combined discharge of the world's next nine largest rivers (OAS, 2005; Reis, Kullander and Ferraris, 2013). Most of the basin's flow (65 percent) comes from the Solimões and Madeira River sub-basins (OAS, 2005). The Amazon River is the largest single source of freshwater runoff in the world, representing some 15 percent to 20 percent of the global river flow (Salati and Vose, 1984). The Amazon River system is divided into 15 sub-basins, containing over 200 tributaries, the largest of which are the Negro, Xingú, Madeira, Tapajós and Juruá sub-basins (OAS, 2005). On average the Amazon transports 600 tonnes to 800 million tonnes of sediment annually, the bulk coming from the Solimões (62 percent) and the Madeira (35 percent) sub-basins (OAS, 2005). The Amazon and its tributaries exhibit predictable monsoonal flood pulses, which can reach an amplitude of 15 m (Junk, 2007). The variation in river discharge, gradient and geology creates a wide range of fish habitats, such as floodplains, wetlands, lakes and flooded forests (Junk ,2007).

Table 37-1. Characteristics of the Amazon River Basin

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
Brazil	3 935 000	63.90	10 989 565	3
Peru	958 000	15.60	10 187 735	11
Plurinational State of Bolivia	721 000	11.70	7 269 961	10
Colombia	342 000	5.60	1 501 416	4
Ecuador	132 000	2.10	3 137 650	24
Venezuela	55 000	0.90	5 317	0.1
Guyana	11 000	0.2	51	2
Total	**6 154 000**	**100**	**33 110 777**	**8**

Fish diversity

The Amazon River contains the largest freshwater diversity on Earth. The extent of species diversity is yet to be determined as many habitats have not been adequately sampled (Junk *et al.,* 2007). As such there are varying figures on the number of species as outlined in Table 37-2. The most abundant fish families are Characidae (224 species), Cichlidae (186 species), Loricariidae (118 species), Rivulidae (56 species), Doradidae (49 species) and Curimatidae (49 species) (FishBase, 2017). The largest species diversity comes from the Amazon lowlands which contain 940 described species, of which 206 are endemic. The Amazon River Basin contains some iconic freshwater species, including the Amazon River dolphin (*Inia geoffrensis*), armoured catfish (*Loricariidae*), arapaima (*Arapaima gigas*), pacu (*Colossoma macropomum*), red-bellied piranha (*Pygocentrus nattereri*) and electric eel (*Electrophorus electricus*) (Petry and Hales, 2013).

Table 37-2. Fish diversity of the Amazon Basin

River	Fish diversity	Endemic
Amazon (whole system)	1 329–2 500	52
Maderia	153	3
Negro	355–658	3
Marañón	69	2
Purús	30	

Sources: Reis, Kullander and Ferraris (2003); Petry and Hales (2015); FishBase (2017).

Fish introductions

The introduction of non-native species in Brazil is prohibited by law. It is thought that the Brazilian Amazon is one of the only sub-basins where non-native species are still scant, but it is also the least studied. Exotic common carp (*Cyprinus carpio*), Nile tilapia (*Oreochromus niloticus*) and *Tilapia* spp. have been introduced for aquaculture purposes (Junk, 2007).

37.2 FISHERIES OVERVIEW

Amazonian fisheries in Brazil are typical freshwater fisheries, where small-scale subsistence fishers produce most of the catch and fish is usually the main source of animal protein consumed by local people (Bayley and Petrere, 1989). Many Amazon fisheries lack knowledge about fish production, fishing gear use and the fish species exploited (Bayley and Petrere, 1989). Amazonian fisheries are mainly categorized into subsistence, commercial, ornamental and recreational classes (Silva and Begossi, 2009). About 200 fish species are used for human consumption, but only about 6 to 12 species make up 80 percent of the fish landings at large cities along the Amazon River (Barthem and Fabré, 2004). The species composition of catch varies according to region, fishery and market. At the Amazon Delta, the most important commercial species are catfish, piramutaba and several species of the family Doradidae. In the Lower Amazon, catfish, maxpará and *Pseudoplatystoma* spp. make up most the catch. In the Middle and Upper Amazon species such as the curimatá and jaraqui are common (Batista, Isaac and Viana, 2004); in the Colombian Andes migrating catfish comprise 90 percent of the catch (Barthem and Fabré, 2004).

Fishing methods

A large variety of fishing gear is employed in the Amazon River Basin. Amazonian fishers use at least 15 types of fishing gear (Batista, Isaac and Viana, 2004). Artisanal fishers generally operate from small craft such as canoes or rafts. Artisanal fishers use cast nets, gillnets, drift nets, harpoons, handlines, tridents, bow and arrow and seine nets (Barthem, Guerra and Valderrama 1995; Batista, Isaac and Viana, 2004). Industrial fleets require commercial permits and use more efficient equipment such as large gillnets and trotlines and can store and preserve fish in ice boxes (de Jesús and Kohler, 2004).

Fish trade

There are no official government estimates for the economic value of capture fisheries in the Amazon River Basin. A valuation study of fisheries activities (primary and secondary industries) from businesses from 15 cities along the Solimões River indicated that the fishing sector generates USD 278 million (Almeida, 2004). Also, the export of tropical fish for the aquarium trade is an important economic sector. Most fish destined for aquariums in Europe and North America come from the Rio Negro. Ornamental fish caught in capture fisheries in Brazil constitute about 5 percent to 10 percent of the global ornamental fish market, and in the Rio Negro, the cardinal tetra (*Paracheirodon axelrodi*) makes up 85 percent of the total catch (OFI, 2002), and 76 percent to 89 percent of all exports each year (Chao, 2001).

Employment

Employment estimates in Amazonian inland fisheries are indicated in Table 37-3. Artisanal fisheries of the Amazon Basin are an important source of employment and income (DFRP, 2001). Generally, for the poor or unqualified, artisanal fisheries are conducted in conjunction with agriculture. The Solimões River, accounts for 45 percent of all fishers in the Amazon River Basin (Bayley and Petrere, 1989). The ornamental fish trade and sport fishing industries employ 1 000 families and 1 000 people per season (Ruffino, 2014). Fishing is considered a locally important livelihood option, but in certain areas it is a highly seasonal (Bennett and Thorpe, 2008). As a result, accurate data on the number of fishers are difficult to find; this is complicated by artisanal fishers often combining fishing with farming and the fishing portion of labour is aggregated into agricultural statistics. In addition, as many parts of the Amazon are remote, accurate counting of fishers is not possible, and in remote areas many subsistence fishers do not join cooperatives of organizations that commercial and artisanal fishers belong to (Bennett and Thorpe, 2008). For instance, Almeida, Lorenzen and McGrath (2003) estimated the number of commercial, artisanal and subsistence fishers in the Western Amazon to be 253 316 people.

Table 37-3. Participation in Amazon River Basin fisheries activities

Fishery	Fishers
Commercial	228 600
Amazon floodplain	49 955
Total	**278 555**

Source: Bayley and Petrere (1989).

Estimated fisheries production

Estimated fisheries production from the Amazon Basin is outlined in Table 37-4. Potential inland fishery production was estimated at 900 000 tonnes/year based on comparisons with other tropical rivers (Bayley and Petrere, 1989). Estimated production in 1991 was 425 000 tonnes/year based on the human population for that year (Bayley, 1998). Of the 1991 production, the proportions from Brazil, Peru, Columbia and Plurinational State of Bolivia were 79 percent, 20 percent, 0.8 percent and 0.7 percent, respectively (Junk, 2007). Catch data for the Amazon River Basin are likely underestimated due to the largely unknown scale of subsistence fishing within the basin. Collecting fisheries statistics from isolated fishing communities is complicated because they tend to catch a large variety of fish, spread over many landing sites, many of which are only accessible by river (Junk, 2007). The quality of some fisheries data is impacted through the lack of agreement among states on a standardized method for data collection (Ruffino, 2014). Subsistence catches in rural areas of Amazonas State, Brazil, remain unrecorded and may total about 113 000 tonnes/year. Similarly, Issac and Almeida (2011) used consumption surveys to estimate that the amount of fish consumed within the Brazilian Amazon was approximately 575 678 tonnes in 2009, considerably higher than the reported fish production of 231 808 tonnes.

Peruvian Amazon River catches have ranged from 80 000 tonnes (Bayley *et al.,* 1992), to 35 000 tonnes (Amazon Waters, 2016). Fish catches are reported at the main ports in each region; however fish statistics are underestimated due to much fish being sold through smaller ports where reporting seldom occurs. As catches from subsistence fishery are never recorded (Barthem, Guerra and Valderrama, 1995), the reported commercial harvest data is expanded by 30 percent (de Jesús and Kohler, 2004).

In Plurinational State of Bolivia, inland fisheries are poorly developed due to communication difficulties and the long distance between fisheries and the commercial fishing centres (FAO, 2005). Therefore, the figures presented in Table 37-4 are likely an underestimation, as fisheries are poorly understood and documented, especially indigenous fisheries, which are the least studied despite the important role they play in the subsistence of aboriginal groups (FAO, 2005).

Table 37-4. Fisheries production estimates for the Amazon River

River/floodplain	Catch estimate (tonnes)	Year	Reference
Amazon (whole system)	425 000	1991	Bayley (1998)
Brazil	575 678	2009	Issac and Almeida (2011)
Peru	35 000	n/a	Amazon Waters (2016)
Plurinational State of Bolivia	9 000	n/a	FAO (2005)
Colombia	34 000	1991	Bayley (1998)
Total	**653 678**		

Note: Total excludes the Amazon (whole system value).

Aquaculture

Changes to Brazilian Law have allowed the transportation and cultivation of more than 2 000 fish species for ornamental aquaculture (Lima, Magalhaes and Vitule, 2015). Aquaculture, particularly in Brazil, is based on small-scale production units, where varieties of native and non-native species are cultured.

Currently, at least 64 aquatic species are raised, mainly non-native tilapias (*Oreochromis* spp.), common carp (*Cyprinus carpio*), native pacu (*Piaractus mesopotamicus*), tambaqui (*Colossoma macropommum*) and catfish (*Pseudopatstoma* spp.) (Roubach *et al.,* 2003).

Recreational fishing

Sport fishing has increased in popularity within the Amazon Basin and attracts many foreign fishers. The main target species is the peacock bass (*Cichla* spp.), with other target species being *Osteoglossum* spp., *Hypophthalmus* spp., *Brachyplatystoma* spp., *Pellona* spp., *Boulengerella* spp., *Hydrolycus scomberoides* and *Raphiodon vulpinus* (IPAAM, 2001). Catch-and-release is the dominant fishing practice amongst national and foreign recreational fishers in the region (Freire *et al.,* 2016). According to the Amazon State Enterprise for Tourism, the number of fishing tourists visiting the state of Amazonas had increased to 7 293 in 2011 (Freire *et al.,* 2016) and the main fishing area is the middle River Negro (Ruffino, 2014).

37.3 THREATS TO THE FISHERIES

Climate change

Climate change predictions indicate an increase in temperature for the Amazon River Basin ranging from 2 °C to 3 °C by 2050 and a decrease in precipitation during dry months (Kattenberg *et al.,* 1996). Climate models predict that the climate of the Amazon will become more extreme and variable (IPCC, 2001). Such disturbances could deplete stocks of adult fish and redistribute aquatic resources (Lake *et al.,* 2000). Recreational and commercial fisheries are considered at risk of climate extremes, as fishery populations are notoriously variable, and fisheries are dependent on strong year classes (Pitcher and Hart, 1982).

Land cover change

Deforestation within the basin has altered at least 697 990 km^2 (10 percent) of the basin area (Eva *et al.,* 2004). Deforestation in the uplands has increased surface runoff and stream discharge through increased evapotranspiration (Neill *et al.,* 2001). In the floodplain areas, deforestation has reduced the diversity of highly productive plant communities that sustain fish populations (Melack and Forsberg, 2001). In the Lower Amazon, 56 percent of the mainstream floodplain was deforested between 1970 and 2008 (Renó *et al.,* 2011). In riparian zones, deforestation can lower water quality, increase water temperature and alter biotic assemblage and production through increased sedimentation and removal of structures that provide habitats for fish (Neill *et al.,* 2001).

River modification

Hydropower accounts for around two-thirds of Brazil's energy supply; there are 154 dams of all sizes in operation, 21 are under construction (Castello *et al.,* 2013) and there are proposals for at least another 334 (Zarfl *et al.,* 2015). Also, the most abundant dams in the Amazon are small farm impoundments constructed to supply drinking water for cattle. In 2007, there were an estimated 10 000 such impoundments in the headwaters of the Xingu Basin alone (Macedo *et al.,* 2013). However, no detailed EIA for dams in the Amazon has been carried out, as most dams were constructed before baseline ecological data were collected (Winemiller *et al.,* 2016).

Water quality

There are two main point and non-point sources of pollution in the Amazon (Castello *et al.,* 2013). One such pollutant is mercury, which is used by artisanal miners to extract gold (Castello and Macedo, 2015). Mercury becomes harmful when anoxic conditions transform mercury into its organic form methylmercury, which is an endocrine disrupter that causes nerve damage and bioaccumulation (Mergler *et al.,* 2007; Zhang and Wong, 2007). Commercial fishes in the Amazon River have methylmercury concentrations higher than those permitted by Brazilian health law (Beltran-Pedreiros *et al.*, 2011). There is no basin-wide information on freshwater ecosystem pollution, except an estimate of 5 000 tonnes of mercury contamination since the start of gold mining in the basin (Junk and Piedade, 2005).

Overexploitation and overfishing

Information on overfishing within the Amazon River Basin is sparse, but an analysis of available population estimates reveals the fishing down of fish populations (Welcomme, 1999). Mean body length of species harvested from the basin in 1895 was ~206 cm, while for 18 species dominating fishery yields in 2007 this was only ~79 cm. Also, the main harvested species in the early 1990s are now considered endangered and four are overexploited in at least one region of the basin (Barthem and Goulding, 2007). Stock assessment for commercially important species indicated that that slow growing species such as the pacu, surubim, dourada and piramutaba were overexploited and their numbers had declined in regional fisheries of the basin (Fabré and Barthem, 2005).

37.4 EQUIVALENT FOOD REPLACEMENT

Fishery activities are of primary importance in the Amazon River Basin. Per capita fish consumption is high; in the Brazilian Amazon consumption now averages 94 kg/capita/year in riverine populations and 40 kg/capita/year in urban populations; consumption rates are 5.8 times and 2.5 times higher than the world average (Isaac and Almeida, 2011).

Given the importance of fish in the diet of populations within the Amazon, particularly indigenous populations and the threats that fisheries within the region face, replacement of capture fisheries was based on a 50 percent loss to the fishery (based on the estimated fisheries total in Table 37-4). Equivalent food replacement estimates are for livestock products (beef, pork and chicken), aquaculture (tilapia and pacu) and crops (cassava and maize).

Table 37-5. Food production (tonnes), water (km^3), land (km^2) and net increase in carbon emissions (million tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in km^3 (percentage of agricultural water use)	Land required to replace fisheries in km^2 (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (million tonnes)
Pacu	205 182 (1409)	0.70 (0.01)	3 077 (0.05)	
Tilapia	193 365 (67.9)	0.58(0.008)	8 789 (0.14)	0.05
Beef	202 927 (1.7)	3.13 (0.05)	23 414 (0.89)	12.70
Pork	106 128 (2.6)	0.64 (0.009)	14 472(0.53)	0.06
Chicken	334 233 (2.0)	1.45 (0.02)	8 968 (0.33)	0.79
Maize	429 451 (0.5)	0.52 (0.008)	765 (0.08)	0.02
Cassava	242 500 (0.9)	0.44 (0.006)	215 (0.02)	

Energy replacement (Table 37-5)

Farmed pacu production within the Amazon Basin countries is not well developed (2015 production was 14 553 tonnes) and replacement of capture fisheries with pacu is equivalent to 1 409 percent of current pacu production within the riparian countries. Farmed tilapia production would require an increase equivalent to 68 percent of current production (2015 production was 284 852 tonnes). The highest replacement value for livestock would come from replacement of fisheries with chicken production, equivalent to 1.99 percent of current production (chicken production in 2014 was 16.80 million tonnes). The largest replacement amount would come from maize production, equivalent to 0.49 percent of current production from riparian countries (2014 maize production was 88.53 million tonnes).

Water demand (Table 37-5)

Replacement of capture fisheries with alternative food sources would have a serious effect on water usage. Beef as replacement would have the largest impact on water demand as the replacement amount is equivalent to 0.05 percent of the agricultural water withdrawals from the riparian countries (agricultural water use was 65.33 km^3 in 2016). Chicken production would require the equivalent to 0.02 percent of agricultural water withdrawals from the riparian countries. Aquaculture products, crops and pork production would require a similar amount of water to replace capture fisheries, equivalent to 0.008 percent to 0.01 percent of current agricultural water withdrawals.

Land requirements (Table 37-5)

Beef production would require the largest land conversion, equivalent to 0.89 percent of pastureland within the riparian countries (pastureland area was 2.71 million km^2 in 2018). Replacement aquaculture production would require land conversions equivalent to 0.05 percent and 0.14 percent of the Amazon Basin area for pacu and tilapia. Chicken production would require the smallest increase in land use from an animal protein source, equivalent to 0.33 percent of the pastureland from the riparian countries. Agricultural crops (maize and cassava) would require the equivalent of 0.08 percent and 0.02 percent respectively of arable land in use from the riparian countries (arable land area was 940 340 km^2 in 2018).

Greenhouse gas emissions (Table 37-5)

Estimated carbon emissions from 50 percent loss to capture fisheries from the Amazon River Basin were 1 288 915 tonnes. Beef as a replacement source would lead to a net increase of 12.70 million tonnes of carbon, considerably higher than the net increase in emissions from chicken, farmed tilapia and pork production (0.79 million tonnes, 0.05 million tonnes and 0.06 million tonnes of carbon, respectively), and maize crops (0.02 million tonnes).

37.5 FISHERIES MANAGEMENT

National management strategies

Current management strategies that cover the Amazon River Basin are only consistent with covering single species and are generally considered inadequate. Government agencies lack sufficient personnel and resources to enforce compliance with regulations, therefore development of commercial fisheries has largely been unregulated. As a result, fishing conflicts between riverine communities and outside commercial fishers have been exacerbated (Fernandez-Baca, 1998; Ruffino, 2001).

In Brazil, centralized approaches to management of fishery resources have been inadequate (Junk, 2007). Management regulations have focused on commercially important or endangered species; such measures address the type of fishing gear, the time and period when fishing is allowed, restriction on access to fishing areas and the use of fishing licences. There is a minimum size of capture for arapaima, pacu and catfish species. Additionally, there are regulations on closed seasons for some species of characins and there are restrictions on the number of vessels and the mesh size used in the commercial fishery for piramutaba (Ruffino, 2014).

In Peru, although legislation exists under Peruvian legislation, fisheries in the Peruvian Amazon have remained largely unmanaged by the state and any regulations that are enforced are usually around urban areas, while state management is almost entirely absent in remote areas. State regulations mainly focus on minimum mesh sizes, closed seasons for certain species and the banning of destructive gear such as explosives and poison. But given the lack of financial resources that the state has, regulations have been difficult to enforce (Ruffino, 2001).

Community-based management

Due to limited government legislation, many riverine communities began to develop and implement their own management regulations, also known as ‘fishing agreements’ or ‘fishing accords’, to protect their own fishery resources and fishing rights (Fernandez-Baca, 1998). Fishing accords claim exclusive rights of access to fishing grounds and establish their own fishing rules with respect to types of gear and closed seasons based on the needs of the community. Although not legally recognized, several such agreements are supported by projects, NGOs or governmental agencies (Ruffino, 2014) and could offer an opportunity for the devolution of state management to resource users (Fernandez-Baca, 1998).

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38 TOCANTINS–ARAGUAIA RIVER

38.1 OVERVIEW

The Tocantins–Araguaia River in Brazil (Table 38-1) covers an extensive catchment comprising 409 116 km² that also incorporates the Itacaiúnas River (Garavello, Garavello and Oliveira, 2010). The Tocantins–Araguaia River has a mean annual discharge of 11 000 m³/s (Cetra and Petrere, 2001). Although part of the Amazon River region, the Tocantins–Araguaia is technically separate from the Amazon River Basin. Despite having linkages to the main course of the Amazon in the southern part of the Tocantins–Araguaia estuary, the Tocantins–Araguaia Basin is almost isolated from the Amazon Basin. The source of the Tocantins River is in the Central Brazilian Plateau; the Araguaia River flows from the foothills of the Serra dos Caiapós and flows parallel to the Tocantins River until they meet. The combined Tocantins–Araguaia River flows for 2 600 km north and is sandwiched between the Paraná–Paraguay, Xingu, Parnaíba and the São Francisco rivers and eventually empties into the Atlantic Ocean. The river is characterized by waterfalls and rapids in the upper reaches, and by slower flowing waters in the middle region. Floodplain lakes are rare in the Tocantins River, but are numerous in the Araguaia River along with lakes. The river experiences a seasonal flood from January to May and a dry season from July to September (Cetra and Petrere, 2001). There are five dams on the Tocantins River.

Table 38-1. Characteristics of the Tocantins–Araguaia River

Country	Area of the river basin (km²)	Percent area of the river in the country	Population of the river basin	Population density/km²
Brazil	915 249	100	9 594 288	10

Fish diversity

The Tocantins–Araguaia River shares several genera and species with the Paraná and São Francisco rivers, which both have their headwaters on the Brazilian Plateau; there is also some species similarity with the Central Amazon River (Garavello, Garavello and Oliveira, 2010). According to FishBase there are 106 species in the Araguaia River, with most species consisting of Characidae (22 species) and Rivulidae (19 species). There are seven endemic species in the Araguaia River: *Ancistrus stigmaticus, Maratecoara lacortei, Melanorivuls violaceus, Pituna obliquoseriata, Plesiolebias fragilis, P. lacerdai* and *Spectrolebias semiocellatrus* (FishBase, 2017).

38.2 FISHERIES OVERVIEW

There are five different types of fishers within the Tocantins–Araguaia River: subsistence fishers who use simple fishing gear such as hand nets; professional local fishers who use motorized boats; professional barrage fishers (mainly in reservoirs); indigenous Kraô fishers who fish for subsistence; and sport fishers (usually tourists) who fish seasonally. Almost half of the total fish catch is concentrated between May and August due to low water levels that increase the density of fish and the emergence of large beaches that facilitate angling (Garavello, Garavello and Oliveira, 2010). In the Tocantins–Araguaia River around 50 fish species are common in fisheries, but the main species are curimatá (*Prochilodus* spp.), piramutaba (*Brachiplastitoma flavicas*), bagres (Pimelodidae), surubin (*Pseudoplastitoma* spp.), tambaquí (*Colossoma macropomum*), branquinha (*Psectrogaster amazonica*) and jaraqui (*Semaprochilodus brama*) (FAO, 2001; Cetra and Petrere, 2001; Zacarkim *et al.,* 2015). In the mid-Tocantins River, schooling migratory curimatá and jaraqui contribute around 70 percent to the fish catch and curimatá is considered the most important fish in the middle reaches of the Tocantins River (Cetra and Petrere, 2001).

Fishing methods

Fishing methods used in the Tocantins–Araguaia River vary according to the type of fishery and the time of year. The main types of fishing gear used in the basin are cast nets, hand nets, gillnets, longlines and beach seines. Gillnets are used in two ways; passively placed in the margins of the river and actively where the fishers leave the net hanging between two canoes and drift downstream; this is known as *caceia.* Gillnet fishing is mainly carried out during the wet season and is responsible for about 90 percent of the yield at this time of year. Beach seining, known as *amarrador*, is prohibited, but it is still used in the *trepeiro* fishery, which is deployed from sand beaches in the dry season and targets curimatá. Overall, 36 percent of fish landed in the Tocantins–Araguaia River are caught by beach seine, 22 percent by cast net and 18 percent by gillnets with the remainder being caught with other net types (Cetra and Petrere, 2001).

Employment

According to MPA (2012), in 2011 the states of Tocantins and Pará had 6 263 and 223 501 fishers, respectively, however, a large portion was most likely fishers from the Amazon River Basin. Zacarkim *et al.* (2015) estimated around 562 fishers on the Araguaia River. Additionally, since the revitalization of the fisheries in the Tucuruí Dam an estimated 10 000 fishers are thought to operate there (Tundisi, Santos and Menezes, 2010). These estimates are likely underestimated as official figures do not state if part-time or subsistence fishers are included and the Zacarkim *et al.* (2015) figure only applies to artisanal fishers.

Estimated fisheries production

Table 38-2 indicates the estimated fisheries production for the Tocantins–Araguaia River. Fisheries data from the Brazilian Ministry of Fisheries and Aquaculture (MPA) were available for the Araguaia, however, Zacarkim *et al.* (2015) estimated that fish catches from the Araguaia River were 5 606 tonnes for 2009, rather than the official estimate of 1 837 tonnes from the MPA. This was based on fishery yields (kg/fisher/day) for both the wet season and dry season, the number of active fishers and the average number of days fished. This would indicate that the estimated production was 205 percent higher than the official estimate. The figure for the Araguaia River supports the view that the highest fisheries landings occurred during the dry season (2 459 tonnes) compared to the wet season (1 279 tonnes) (Zacarkim *et al.,* 2015). This would suggest some irregularities in the collection and analysis of data, and that the fisheries production for the Tocantins River is also underestimated. Fish catches for the Tucuruí Dam have increased since it was closed in the 1980s, however, the figure in Table 38-2 could be overestimated as most fish from some monitored landing sites within the Tocantins Basin are brought in from other regions in Brazil and could be counted twice (MPA, 2011).

Table 38-2. Estimated fisheries production from the Tocantins–Araguaia River

Waterbody	Catch estimate (tonnes)	Year	Reference
Tocantins River	3 424	2011	MPA (2012)
Araguaia River	5 606	2006	Zacarkim *et al.* (2015)
Tucuruí Dam	7 330	2005	MPA (2012)
Total	**16 360**		

Status of the fisheries: catch trends

Catch trends and the state of the Tocantins–Araguaia fisheries are not well known; there have been many studies on the species diversity of the river but very few studies on its fisheries. Upstream of the Tucuruí Dam in the reservoir a new fishery has been created and fishing activities have expanded. Since the 1980s there has been an increase in the number of fish landing sites on the reservoir, but scant infrastructure has been adapted to manage the increased amount of fish in the area (MPA, 2012). Fisheries production increased from 414 tonnes between 1981 and 1982 to 7 330 tonnes in 2011 (MPA, 2012). Fisheries production below the Tucuruí Dam after its establishment was decimated and catches dropped by about 60 percent compared to pre-impoundment (Fearnside, 2001). For instance, in Cametá (in Pará State) there was a decline from 4 726 tonnes before the impoundment to 831 tonnes in 1987 after the impoundment (Odinetz-Collart, 1993). This has been partially attributed to the reduction in stocks leading to an increase in prices, which discouraged consumers and encouraged a shift in diet towards chicken, beef and farmed tambaquí from local fish farms (MPA, 2012).

Aquaculture

According to the MPA, the Brazilian states that the Tocantins–Araguaia River flows through produced 36 339 tonnes of fish via aquaculture in 2011. Specific breakdown of species cultured within the basin is not known, but the most common species cultured are tilapia (*Oreochromis* spp.), common carp (*Cyprinus carpio*) and tambaquí (*Colossoma macropomum*) (MPA, 2012).

Recreational fisheries

Due to its high species richness, the Tocantins–Araguaia River is a popular destination for sport fishing. Participation or fish catches from the basin are not known, but popular angling species include catfish (*Phractocephalus hemioliopterus, Arapaima, Pseudoplaystoma* spp. and *Astroblepus cacharas*) freshwater barracuda and peacock bass (*Cichla* spp.) (Palmas Tocantins Brazil, 2017).

38.3 THREATS TO THE FISHERIES

Habitat modification

The construction of the Tucuruí hydroelectric dam had huge environmental and social implications for fish and the livelihoods of fishers in the Tocantins River Basin. The Tucuruí Dam inundated 2 430 km^2 of land, 47 percent more than was predicted in the preconstruction monitoring phase and displaced 32 871 people (Fearnside, 2001; International Rivers, 2017). Of the 280 species that dwelled in the river before the dam was constructed, only 178 species now occupy the reservoir (Tundisi, Santos and Menezes, 2010). No fish ladder was built at the Tucuruí Dam, most likely due to cost issues and uncertainty about its effectiveness (Fearnside, 2001). This blocked the migration route for fish species, and as such, the diversity of fish species in the impoundment declined drastically, with fish communities becoming dominated by a few species (Leite and Bittencourt, 1991). Commercial fishing was prohibited in the reservoir until the end of 1985; in 1986 the commercial catch increased rapidly owing to a population explosion of predators. However, at the same time, the fish biomass was declining, and by 1987 the CPUE began to decline (Fearnside, 2001). The Brazilian Government plans to build a cascade of dams on the Tocantins and Araguaia Rivers; seven dams are planned for construction and one is already under construction on the Tocantins River. In the Araguaia River two dams are already under construction but the planned construction of a further two dams poses a major threat to indigenous peoples. Another threat to the Tocantins–Araguaia River is the plan to channelize and blast rock outcroppings along 1 782 km of the Rio das Mortes (a major tributary of the Araguaia) and Tocantins River to construct an industrial highway to lower the cost of soybean transportation (International Rivers, 2017). If these plans go ahead this will have further implications for the fish and fisheries populations of the Tocantins–Araguaia River.

Water quality

Despite recommendations that 85 percent of the vegetation be removed from the flood area before the impoundment of the Tucuruí Dam, only 30 percent of vegetation was actually removed (Monosowski, 1986). The mass of decomposing vegetation left when the lake filled combined with the thermal and chemical stratification and anoxic deep layers meant that water passing through the turbines was low in oxygen. This water did not mix with water from the spillway for about 60 km downstream of the dam, which reduced the fish populations below the dam (Monosowski, 1990). The combined effects of the decomposition of biomass, the proliferation of aquatic weeds and stagnation of the water created ideal conditions for the generation of methane, ammonia and hydrogen sulphide (Tundisi, Santos and Menezes, 2010), which rendered the water unsuitable for many fish species (Fearnside, 2001).

38.4 EQUIVALENT FOOD REPLACEMENT

Due to the heavy modifications of the Tocantins–Araguaia River and their impact within the basin, and considering the future planned dam development, equivalent food replacement estimates were established based on a 50 percent loss to the fishery production figures in Table 38-2. Replacement food sources consist of aquaculture products (farmed pacu and tilapia), livestock (beef, pork and chicken), and cassava.

Table 38-3. Food production (tonnes), water (million m³), land (km²) and net increase in carbon emissions (thousand tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (thousand tonnes)
Cachama	5 135 (3.8)	17.6 (0.04)	77 (0.008)	
Tilapia	4 839 (2.20	14.4 (0.03)	219 (0.02)	1.26
Beef	5 078 (0.05)	78.3 (0.2)	586 (0.03)	317.9
Pork	2 656 (0.08)	15.9 (0.04)	362 (0.02)	1.47
Chicken	8 365 (0.07)	36.2 (0.08)	224 (0.01)	19.81
Cassava	6 069 (0.03)	11.1 (0.02)	6 (0.0007)	

Energy replacement (Table 38-3)

Aquaculture practices would need to increase to replace capture fisheries in the Tocantins–Araguaia River Basin. Chicken and cassava would require the largest production increase, equivalent to 0.1 percent and 0.03 percent of production in 2014 (2014 chicken and cassava production was 12.5 and 23.3 million tonnes, respectively). Pork would require the smallest increase in production, equivalent to 0.04 percent of production in 2014 (2014 pork production was 3.2 million tonnes).

Water demand (Table 38-3)

Beef production would have the largest impact on water resources in Brazil, equivalent to 0.2 percent of agricultural water use from Brazil (agricultural water use was 44.9 km³ in 2010). Water demand from chicken production is roughly half that of beef production and is equivalent to 0.08 percent of the agricultural water usage in Brazil. The remaining replacement food sources would require a similar amount of water representing 0.02 percent to 0.04 percent of agricultural water usage in Brazil.

Land requirements (Table 38-3)

Beef production would require the largest land conversion of 586 km² of land to replace capture fisheries, equivalent to 0.03 percent of pastureland in Brazil (2 million km² in 2014). Farmed cachama and tilapia would require land conversion equivalent to 0.008 percent to 0.02 percent of the Tocantins–Araguaia Basin area. Pork and chicken production would require 362 km² and 224 km² of land to replace capture fisheries, equivalent to 0.02 percent and 0.01 percent of permanent pastureland in Brazil.

Greenhouse gas emissions (Table 38-3)

Carbon emissions from 50 percent of capture fisheries production in the Tocantins–Araguaia River were estimated at 30 756.70 tonnes. Net increases in carbon emissions from replacement of capture fisheries with alternative food sources would be highest for beef production (317 967 tonnes). Chicken production would have the next highest emissions increase of 19 813 tonnes, followed by pork (1 469 tonnes) and farmed tilapia (1 259 tonnes).

38.5 FISHERIES MANAGEMENT

Management of fisheries in Brazil is mainly the responsibility of the federal government, specifically the Brazilian Environmental and Renewable Natural Resources Institute, which is responsible for monitoring the status of stocks and for setting and enforcing regulations. In areas not covered by specific legislation, fishing is controlled by an administrative ordinance that covers all inland waters. However, this regulation is flawed as it considers all inland waters as a single environment. Fishing methods and access are controlled through closed seasons during spawning migrations, limits on mesh sizes, minimum catch sizes and prohibition of damaging gear; however, enforcement of measures is not effective (Ruffino, 2001).

Currently, there are five protected areas in the Tocantins–Araguaia River Basin. The biological reserve of Águas Emendadas and Chapada dos Veadeiros National Park protect the headwaters of the Tocantins River. The National Park and Indigenous Reserve of Araguaia preserve the middle Araguaia floodplains, and a small biological reserve north of Mocajuba preserves part of the lower Tocantins landscape (Garavello, Garavello and Oliveira, 2010).

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39 LAKE TITICACA

39.1 OVERVIEW

Located between the Plurinational State of Bolivia and Peru at 3 180 m above sea level, Lake Titicaca is the largest freshwater lake in South (Table 39-1). With a volume of 923 km^3 it is one of the highest navigable lakes in the world. The lake consists of two sections: the deep main basin (Lago Mayor) and the smaller and shallower Lago Pequeño (Arze and Quintanilla, 1991). Most of the water input comes from glacial melt and rainfall via the tributaries that feed into the lake such as the Rio Suches. Lake Titicaca has a small outlet in the Plurinational State of Bolivia (the Rio Desaguadero) but it is estimated that over 90 percent of the water that enters the lake evaporates (Carmouze and Jaen, 1981). The Rio Ramis is the largest and longest (2 000 km) tributary that drains into the lake; other important watercourses include the Ilave, Coata and Huancane rivers (Gammons *et al.,* 2006). Despite the tropical location, temperatures seldom exceed 17 °C (Wurtsbaugh and Tapia, 1988), consequently the lake is oligotrophic and cold with a high salt concentration (Monroy, Maceda-Veiga and de Sostoa, 2014).

Table 39-1. Characteristics of Lake Titicaca

Country	Area of lake (km^2)	Percent area of the river in countries
Plurinational State of Bolivia	5 135	60
Peru	3 424	40
Total	**8 559**	**100**

Source: Gammons *et al.* (2006).

Fish diversity

Fish fauna populations of high elevation lakes and streams are not particularly high; however, endemism is very high. Fish fauna of Lake Titicaca comprise native and exotic species. The native fauna constitute 40 species in only three genera: climbing catfish (*Astroblepus*), pupfish (*Orestias*) and the pencil catfish (*Trichomycterus*). *Orestias* is the dominant genus with 36 species (90 percent), of which 34 are endemic (FishBase, 2017).

Fish introductions

The purpose of fish introductions into Lake Titicaca was to create a commercial fishery in one of the densest and poorest areas of the Andes. The pelagic zone of the lake was very species-poor in comparison with its littoral fish assemblage (Vaux *et al.,* 1988). Introductions of lake trout, lake whitefish and cisco were recommended by the US Bureau of Commercial Fisheries. However, the introduction of lake trout failed, but brown trout and rainbow trout introduced in the 1940s, followed by pejerrey, native to Argentina, in the 1950s were successful (Wurtsbaugh and Tapia 1988; Hall and Mills, 2000).

39.2 FISHERIES OVERVIEW

Fisheries resources are economically important as a source of income and food for local communities around Lake Titicaca (Monroy, Maceda-Veiga and de Sostoa, 2014). Lake Titicaca supports an artisanal and commercial fishery, with low capitalization, simple gear use and small fishing craft (Levieil and Orlove, 1990). Lake Titicaca fisheries are not spatially concentrated; fishing is usually practised by individuals from lakeshore communities (Bustamante and Treviño, 1976). Most fishers operate from reed rafts or small wooden boats; only a minority (less than 5 percent) own outboard motors (Levieil and Orlove, 1990). Fishers tend to spend less than a third of labour time fishing but receive between half and three-quarters of their income from fishing as it offers higher returns compared to other livelihood activities. Fishers also participate in agricultural and other cash-generating activities to supplement their income (Levieil, 1987). About two-thirds of the catch is sold for cash, while the remainder is consumed directly and bartered for foodstuffs (Orlove, 1986).

The Lake Titicaca commercial fishery is dominated by two species of non-native fish: rainbow trout and pejerrey (Vaux *et al.,* 1988). Although some rainbow trout are still caught in the tributaries of the lake, the numbers are not thought to be significant. Fishers participate in four fisheries: the demersal gillnet fishery for native species such as carachi, the pelagic fishery for introduced species like pejerrey, and the trawl fishery and *O. ispi* fishery which are of lesser economic importance (Levieil and Orlove, 1990).

Fishing methods

Most (90 percent) fishing is carried out with nylon gillnets, but some fishers also use push nets, seines and trawls (Alfaro *et al.,* 1982). The demersal gillnet fishery uses multifilament nylon nets with mesh sizes between 38 mm and 63 mm along the lake bottom. The pelagic fishery for pejerrey, which also uses gillnets, uses nets with mesh sizes between 63 mm and 152 mm. The *O. ispi* fishery, undertaken at night, uses beach seines or small trawls and catches fish close to shore when they come to spawn or feed (Bustamante and Treviño, 1976; Levieil and Orlove, 1990).

Fish trade

During the height of the rainbow trout commercial fishery, high fish catches promoted the development of foreign and locally owned canneries, which exported their products to Europe, the United States and Australia (Laba, 1979). Current estimates of the fisheries trade from Lake Titicaca are unknown, but it is likely that most, if not all, of the fish are consumed and sold within the basin.

Employment

Table 39-2 indicates the estimated participation in fisheries around Lake Titicaca. Estimates for participation from the Peruvian portion of the lake were not available but are likely higher than the Bolivian portion. The figure in Table 39-2 represents commercial fishers only in 1993 and does not include occasional fishers and those who fish for subsistence. The number of people who derive some of their livelihood from trout aquaculture has increased, alleviating poverty. In Peru, cage culture operations assisted some 200 families in setting up 33 microenterprises to culture trout; within these enterprises more than 50 percent of the operations are run by women (Halwart, Soto and Arthur, 2007). Vila, Pardo and Scott (2007) estimated that about 6 000 people who live around the lake operate net cage culture for trout.

Table 39-2. Participation in Lake Titicaca fisheries activities

Country	Fishers
Plurinational State of Bolivia	1 258

Source: FAO (2005).

Estimated fisheries production

Estimated fisheries production from Lake Titicaca is outlined in Table 39-3. Generally it is assumed that the biomass of the fishery represents a major food source for the human population, but the fish stocks of the lake have been subject to scant investigation and consequently are little understood. The potential fishery production from Lake Titicaca was estimated at between 40 000 tonnes/year to 60 000 tonnes/year, although fishery production has rarely exceeded 10 000 tonnes/year (FAO, 2005). The production figure in Table 39-3 is not likely to reflect what is occurring within the fishery due to the general lack of fishery information.

The fisheries sector in the Plurinational State of Bolivia has experienced institutional changes over the last 50 years; the Department for Fisheries Development was created and dissolved within ten years and the Fisheries Development Centre (FDC) was developed. The FDC's main functions are revenue collection and registration of catches, which means stock assessment and research are not carried out on the lake and the CDP's development of the sector and people employed in it has been minimal (Vila, Pardo and Scott, 2007). Consequently, the fishery estimate in Table 39-3 is not likely to be a true representation of actual fish production.

Table 39-3. Production estimates for Lake Titicaca

Country	Catch estimate (tonnes)	Year	Reference
Plurinational State of Bolivia	2 000	n/a	FAO (2005)
Peru	8 160	1980	Orlove (1986); Levieil (1987)
Total	**10 160**		

Status of the fisheries: catch trends

The rainbow trout fishery was initially successful within the lake but appeared to follow the pattern common to many exotic species: a population boom followed by a rapid decline (Laba, 1979). The fishery eventually closed in 1969 as it had become increasingly unprofitable (Laba, 1979). The cause of collapse of the rainbow trout fishery has been blamed on several factors: the collapse of forage, increase in fishing effort and overfishing, and an increase in competition and predation pressure by the more successful pejerrey (Hall and Mills, 2000; Gammons *et al.,* 2006).

Aquaculture

Aquaculture is not well developed within the Lake Titicaca Basin, but it is starting to develop. Small-scale cage production of rainbow trout has developed within the lake with the aim of reducing poverty. Trout production grew from 5 475 tonnes in 2005 to 32 527 tonnes in 2014 (Oxford Business Group, 2017).

Recreational fisheries

The pejerrey was originally introduced by the Bolivian Oruro Sport Fishing Club for anglers who wanted a more challenging fish to catch (Orlove, 2002). Recreational sport fishing for rainbow trout is popular with tourists, who fish along the lake and its tributaries; however no indication of the amount caught, or economic value of the industry is available.

39.3 THREATS TO THE FISHERIES

Climate change

Climate change has been an overwhelming factor in the transformation of the lake, with increased solar radiation in the Andean highlands, accompanied by a decrease in rainfall and a shortening of the rainy season. Glacial melt in the Peruvian Andes, where most of the tributaries that feed Lake Titicaca are sourced, has accelerated and the glaciers have shrunk by about 49 percent in the last 40 years. Lower water input into the lake has induced the lowest lake level since 1949, with 80 cm lost in six months. Modelling has indicated that predicted temperature rises of 2 °C globally could cause Lake Titicaca to shrink by as much as 85 percent (Eye on Latin America, 2017).

Water quality

The location of artisanal mining areas upstream in the tributaries of Lake Titicaca, in the Rio Ramis, Coata and Ilave represents a significant source of metal pollution into the lake. Metals such as copper, zinc, cobalt, iron, cadmium, lead and mercury have been identified in Lake Titicaca fish species (Monroy *et al.,* 2014). Fish sampled from areas near these tributaries had high levels of heavy metal pollution. The metal concentrations in four fish species (pejerrey, two species of *Orestias* and one species of catfish) collected by Monroy, Maceda-Veiga and de Sostoa (2014) exceeded the threshold established by European and American legislation, with the exception of cobalt, copper and iron. Hurtado, Gonzáles and Steenland (2006) asserted that the discharge of mining waste has reduced the fish biomass of the lake by 45 percent.

Given that many people are dependent on the fishery for food, the high concentration of heavy metal toxins is a cause for concern. Monroy, Maceda-Veiga and de Sostoa (2014) encouraged the use of legislation to reduce metal pollution and limit consumption of certain species. Additionally, a growing population around the lakeshore has led to an increase in untreated sewage from households and industry. This has led to the proliferation of duckweed around the bay areas of the lake (Global Nature Fund, 2012).

Invasive species

The introduction of exotic species into Lake Titicaca led to a protozoan infestation of *Ichthyophthirius multifiliis* in native killifishes (*Orestias* spp.) during the 1980s. This caused the mortality of 206 tonnes of commercially important fishes, 70 percent of which were adults (Wurtsbaugh and Tapia, 1988). The parasite penetrates the skin and gill epithelium and causes mortality when infestation is high (Amlacher, 1970). The parasite is considered one of the most dangerous freshwater parasites of cultured species, but it is rarely reported in native fish. The parasite is believed to have been spread by introduced rainbow trout as they are known carriers (Wurtsbaugh and Tapia, 1988).

39.4 EQUIVALENT FOOD REPLACEMENT

In the remote area of Lake Titicaca, fishing is likely to make up a sizeable portion of the animal protein intake and for the fishers of the lake, most of their income comes from fishing. Due to the lack of alternative livelihood options that can generate enough income to meet the income needs of communities around the basin, equivalent food replacement was based on a 50 percent loss to the estimated fisheries catch (Table 39-3). Replacement food sources consisted of livestock (beef, pork and chicken), aquaculture (rainbow trout and pacu) and crops (cassava and maize).

Table 39-4. Food production (tonnes), water (million m³), land (km²) and net increase in carbon emissions (thousand tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (thousand tonnes)
Pacu	3 189 (21.9)	10.9 (0.08)	48 (0.6)	
Rainbow trout	3 878 (9.1)	17.0 (0.1)		2.94
Beef	3 154 (0.8)	48.6 (0.3)	363 (0.07)	197.47
Pork	1 649 (0.7)	9.9 (0.07)	224 (0.04)	0.91
Chicken	5 194 (0.3)	22.5 (0.2)	139 (0.03)	12.30
Maize	6 674 (0.3)	8.2 (0.06)	12 (0.01)	0.26
Cassava	3 769 (0.3)	6.8 (0.04)	4 (0.004)	

Energy replacement (Table 39-4)

Farmed pacu and rainbow trout production to replace kilojoules from capture fisheries is equivalent to 21.9 percent and 9.1 percent of current production (2015 production of farmed rainbow trout and pacu was 42 490 tonnes and 14 553 tonnes, respectively). Replacement with maize would require an increase equivalent to 0.3 percent of current maize production in the riparian countries (maize production in 2014 was 2.6 million tonnes). Similarly, replacement with chicken would require a high replacement value of 5 100 tonnes, equivalent to 0.3 percent of current production (chicken production in 2014 was 1.7 million tonnes).

Water demand (Table 39-4)

Beef as a replacement source would have the largest impact on freshwater resources, equivalent to 0.3 percent of agricultural water withdrawals from the Plurinational State of Bolivia and Peru (agricultural water use was 14.05 km^3 in 2016). Aquaculture species, rainbow trout and pacu would require equivalent to 0.1 percent and 0.08 percent of current agricultural water withdrawals.

Land requirements (Table 39-4)

Farmed pacu as a replacement food source would require land-use conversion, equivalent to 0.6 percent of the Lake Titicaca area. Beef would require the largest land conversion, equivalent to 0.07 percent of pastureland from the Plurinational State of Bolivia and Peru (2014 pastureland area in the Plurinational State of Bolivia and Peru was 518 000 km^2). Maize and cassava would require 12 km^2 and 4 km^2 to replace capture fisheries, equivalent to 0.01 percent and 0.004 percent of arable land in the Plurinational State of Bolivia and Peru (arable land area in the Plurinational State of Bolivia and Peru in 2014 was 86 241 km^2).

Greenhouse gas emissions (Table 39-4)

Estimated greenhouse gas emissions from 50 percent estimated capture fisheries were 19 100 tonnes. Replacement of capture fisheries with alternative food sources would result in a net increase in carbon emissions. Replacement with maize would have the smallest net increase in emissions of 236 tonnes, followed by production of pork (912 tonnes), rainbow trout (2 947 tonnes), chicken (12 304 tonnes) and beef (197 466 tonnes).

39.5 FISHERIES MANAGEMENT

National management strategies

In the Plurinational State of Bolivia, the FDC is responsible for control, policing and registering of official catches. Bolivian legislation considers water in all areas to belong to the state and the protection and conservation of the resource are fundamental tasks of the state and society (Vila, Pardo and Scott, 2007).

In Peru, the Cabinet of Production is a primary driver organization for Peruvian industry and fisheries. As with Bolivian law, Peru also considers natural resources, including water, as state property and assumes protection and conservation of the resource. The state applies the norm for environmental and biodiversity protection, applying the principle of 'who contaminates pays' guaranteeing the maintenance of all species and their ecosystems (Vila, Pardo and Scott 2007).

Local management systems

Local communities of Lake Titicaca manage aquatic resources through a system of communal fishing territories. Each communal fishing territory is associated with a specific lakeshore community and a specific portion of aquatic space, to which community members have exclusive rights. Sanctions are brought against outsiders who cross territory boundaries. Community members are the only people who have rights to fish within the territory and access to the fishery is open to all members of that community. Although not legally enforced, local communities abide by these regulations (Levieil and Orlove, 1990).

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40 LA PLATA RIVER

40.1 OVERVIEW

The La Plata River Basin (Table 40-1) is the second largest river basin in South America and fourth largest in the world (Bereciartua and Novillo, 2002; Quirós, 2004). It is divided into the Paraná, the Paraguay and the Uruguay river sub-basins (Quirós, 2004). The Paraná River flows 3 740 km from its source in the Precambrian Brazilian Shield to its mouth in the Pampa Plain. The Paraguay River extends from its source in the Western Brazilian Shield to its confluence with the Paraná River. The Uruguay River flows 1 800 km from its source in Southern Brazil into the La Plata River. The Pantanal Wetlands, located in the upper Paraguay River Basin, is the largest freshwater wetland in the world, covering 140 000 km^2 (Living Lakes Partnership, 2005). The La Plata River and its tributaries experience seasonal flood pulses, which are considered an important environmental phenomenon in the Pantanal region that influences ecological processes (Barletta *et al.,* 2016).

Table 40-1. Characteristics if the La Plata River Basin

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
Brazil	1 413 388	47	73 513 025	52
Argentina	841 651	28	28 128 403	33
Paraguay	399 344	13	6 633 003	17
Plurinational State of Bolivia	221 902	7	1 444 452	7
Uruguay	139 150	5	3 045 562	22
Total	**3 015 434**	**100**	**112 764 446**	**26**

Fish diversity

The La Plata River covers a wide variety of habitats, which is reflected in the large fish diversity (Table 40-2). Most of the species belong to the Orders Characiformes (36 percent to 46 percent) and Siluriformes (37 percent to 43 percent) (Quirós, Bechara and de Resende, 2007). Quirós, Bechara and de Resende (2007) listed 591 species for the La Plata Basin, with 85 endemic species (Revenga *et al.* 2000). Individually, 271 species are listed for the Paraguay River, 482 for the Paraná River and 241 for the Uruguay River (FishBase, 2017). The La Plata Basin is habitat to the La Plata river dolphin and the only species of lungfish found in the neotropics (WWF, 2005). However, these species lists are incomplete, and new species are continually being found (Quirós, Bechara and de Resende, 2007).

Table 40-2. Fish diversity of the La Plata Basin

River	Fish diversity	Endemic species	Introduced species
La Plata River	591	85	
Paraguay River	271	8	-
Paraná River	482	20	-
Uruguay River	241	16	4

Sources: Quirós, Bechara and de Resende (2007); FishBase (2017).

Fish introductions

According to FishBase, there are four invasive species in the Uruguay River: the Nile tilapia (*Oreochromis niloticus*), North African catfish (*Clarias gariepinus*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) (FishBase, 2017). In the Upper Paraná River, the tunanare bass (*Cichla monoculus*), *Cichla piquiti* and *Plagioscion squamosissimus* were introduced for sport fishing and make up 25 percent and 18 percent of fish catches in the Upper Paraná reservoirs and Paraná River (Quirós, Bechara and de Resende, 2007).

40.2 FISHERIES OVERVIEW

Fishing is a socially and economically important activity in the Pantanal. Currently, the Pantanal exhibits subsistence, professional–artisanal and sport fishing. Professional fishing is carried out on a small scale by independent fishers who are organized into professional associations. The rise of sport fishing led to the creation of a live bait fishery, which has become an important source of income for many fishers (Barletta *et al.,* 2016). From the 1980s a downturn in professional fishing occurred, as a shift in focus to fishing tourism expanded to satisfy a growing number of sport fishers. Nets and cast nets were banned, which decreased the capture fishery, affecting professional fishers (Mateus, Vaz and Catella, 2011). In the Upper Paraná, commercial fisheries are the most common, with most practised in reservoirs with fishers living exclusively on the fisheries. Artisanal fisheries are carried out mainly in rivers and floodplain areas, but fishers rarely conduct fishing full time as they also participate in small-scale agriculture (Barletta *et al.,* 2016). Generally, the fishing effort is multispecific but the most common species are migratory; however small numbers of large piscivorous and potamodromous fish are still captured. Migratory whitefish are the main species caught by subsistence fishers; 'blackfish' species (*Hoplias malabaricus*) and piranhas (*Serrasalmus* spp. and *Pygocentrus nattereri*) are used for food (Quirós, Bechara and de Resende, 2017).

Fishing methods

In some regions of the Pantanal, the main types of gear are gillnets, trawl seines, longlines and cast nets. There are legal restrictions for the use of nets during the reproductive season (Resende, 2000). Over most of the Pantanal, fishing with nets was banned in the 1980s; currently hook and line is the only equipment allowed, except for live bait fishing (Mateus, Vaz and Catella, 2011) and cast nets are allowed only for catching corimba (Petrere *et al.,* 2002). Recreational fishers are permitted to fish using hook and line from motorized boats (Barletta *et al.,* 2016). In the Upper Paraná commercial fishery, motorized boats and a wide range of gear, including gillnets and longlines, are used. The artisanal fishery uses simple gear such as hook and line (Barletta *et al.,* 2016).

Fish trade

Inland fisheries are generally underdeveloped in terms of economic value and processing of products. Most fish are marketed as either fresh or frozen through local or regional markets. The only sector with an applicable economic value is the sport-fishing sector which, in the Pantanal region, is worth about USD 35 million to USD 56 million annually (Shrestha, Seidl and Moraes, 2002).

Employment

The estimated participation in the La Plata river fisheries is outlined in Table 40-3. However, the number of commercial and subsistence fishers is likely to differ from those in Table 40-3. Firstly, the figures in Table 40-3 reflect the number of fishers registered by the Brazilian Ministry of Fisheries and Aquaculture (MPA) and does not include the participation of fishers from the other basin countries where data were unavailable. Secondly, according to Barletta *et al.* (2016) the number of active fishers is lower than Table 40-3 suggests, as many only register to access benefits.

Table 40-3. Participation in La Plata River Basin fisheries activities

Type of fishing	Fishers
Commercial/subsistence	10 300
Recreational	46 000
Total	**56 300**

Sources: Shrestha, Seidl and Moraes (2002); Barletta *et al.* (2016).

Of the 345 000 fishing licences issued in 2012, 37.4 percent of fishers declared a preference for fishing in the Pantanal (MPA, 2013). In the Upper Paraná, many people entered the fishery after the construction of dams in the upper reaches was completed creating high unemployment among worker populations involved in dam construction and landowners who lost farmland (Barletta *et al.,* 2016).

40.3 ESTIMATED FISHERIES PRODUCTION

Table 40-4 indicates the production estimates from available literature and Table 40-5 shows the CPUE from the different tributaries of the La Plata River. Landing statistics are not available on a regular basis throughout the La Plata Basin, but fisheries are dominated by sport fishing. As such, the figures in Table 40-4 are likely underestimated due to the lack of information available. The fisheries of the La Plata Basin are controlled by restrictive fishery regulations, which undervalue the productivity and food value of the river (Catella, 2003). Generally, when diverse fishing gear was allowed for commercial and subsistence fisheries, the total catch was around 2 800 tonnes/year of which sport fishing only constituted 25 percent of the catch. In 1994, sport fishing constituted 72 percent of the catch and commercial fisheries 28 percent of the 1 450 tonnes annual total (Catella *et al.,* 1997).

Table 40-4. Production estimates for the La Plata River

Waterbody	Catch estimate (tonnes)	Year	Reference
Itaipu Dam	1 192	1998	Agostinho, Okada and Ambrosio (1999)
Middle Paraná	60 000	n/a	Quirós, Bechara and de Resende (2004)
Pantanal Wetlands	1 450	1995	Catella *et al.* (1997)
Cuiaba River	1 207	2000–2001	Mateus, Penha and Petrere (2004)
Total	**63 849**		

Table 40-5. Catch per unit effort from the La Plata River

Waterbody	CPUE (kg/fisher/day)	Reference
Upper Paraná	10–15	Quirós (2004)
Lower Paraná	110	
Middle Paraná	110	
Pantanal Wetlands	2	Neto and Mateus (2009)
Paraguay River	8–10	Quirós (2004)
La Plata	300	

Status of the fisheries: catch trends

Catches from the Pantanal Wetlands have declined since the 1980s with the introduction of new fishing regulations aimed at sport fishers. Average fish landings in the 1980s were 2 206 tonnes/year when nets were allowed (Catella *et al.,* 1997). There are currently no data available for fisheries landings in the northern Pantanal, where estimated yield was 4 862 tonnes/year in the 1980s (Catella *et al.,* 1997). Fisheries in the Itaipú Dam, before impoundment, were dominated by migratory species with high commercial value. After inundation, fisheries were replaced by smaller less valuable species (Barletta *et al.,* 2016), consequently the total yield dropped by half in 15 years and the CPUE dropped from 23.3 kg/fisher/day to 8.7 kg/fisher/day between 1987 and 2005 (Barletta *et al.,* 2016). Generally, fisheries in the Upper Paraná reservoirs are considered an unprofitable occupation.

Aquaculture

There is little information regarding fish farming within the La Plata Basin, and aquaculture of native species is considered an unimportant activity due to the abundance of wild fish. Aquaculture of pacu, some catfish species and *Prochilodus* species has been developed but production figures are unknown (Quirós, Bechara and de Resende, 2007). Additionally, to compensate for the decrease of valuable fisheries, several species have been cultured for stocking, including tilapia (*O. niloticus*) and common carp (*Cyprinus carpio*) (Agostinho, Okada and Ambrosio, 1999).

Recreational fishing

Sport fishing is hugely popular within the La Plata Basin, with the most popular destination being the Pantanal Wetlands. Most sport fishers are from southern and southeastern Brazil; they can only fish with a licence and must adhere to strict fishing regulations. Characiformes and larger fish species are the primary target of sport fishers, with pacu making up roughly 23 percent of catches. Also, introduced species (tunanare bass, *Cichla piquiti* and *Plagioscion squamosissimus*) are common sport fish. The current average catch per fisher is estimated at 2 kg/fisher/day in the northern Pantanal (Neto and Mateus, 2009). Roughly 43 000 sport fishers participate in sport-fishing activities annually (Shrestha, Seidl and Moraes, 2002).

40.4 THREATS TO THE FISHERIES

Dam construction

There are approximately 75 large dams and 452 smaller dams within the La Plata River Basin. The three main dams are the Itaipú, the second-largest dam in the world, on the Paraná River; the Salto Grande on the Uruguay River; and the Yacyretá on the Paraná River. River regulation in the Upper La Plata Basin was considered one of the primary factors for reducing fish diversity (Agostinho and Gomes, 1997). Even unregulated rivers may be impacted by upstream dams, which create unsuitable habitat for fish that are adapted to normal channel conditions (Quirós, 2004). There are several signs that fish assemblages are stressed in the lower basin (Quirós, 1990). Changes to fish species composition in commercial landings in the lower basin have been reported. The abundance of migratory fish has diminished and the size of potamodromous fish has decreased. In addition, several species of mainly fruit- and seed-eating fish have disappeared from zones where they were abundant during the predevelopment phase (Quirós, Bechara and de Resende, 2007). There has also been a noticeable decrease in the frequency and size of top predators in landings from the Lower Paraná (Quirós, 1990). Additionally, mass fish kills have been reported in the Upper Paraná due to gas supersaturation (Bechara *et al.,* 1996). Efforts to offset the impact on migratory fish with the construction of fish passes have largely been unsuccessful as few dams in the upper basin have fish passes, and those that do have fish passes have very low efficiency (e.g. fish elevators on the Yacyretá Dam have target efficiency of less than 2 percent) (Oldani *et al.,* 2007).

Land-use change and water pollution

The development of agriculture and mining within the La Plata Basin resulted in large areas of the basin being impacted by deforestation and pollution. In the Upper Uruguay Basin, forest cover is estimated at only 2.6 percent of forest cover that existed at the start of the century (Tucci and Clarke, 1998). In addition, deforestation along the Upper Paraná and Paraguay River has led to increased river flow from surface runoff, erosion and sedimentation (Barletta *et al.,* 2016). Mining discharges are another source of pollution that is a particular problem in the Upper Paraguay River. In the upper basin, heavy metal levels are the main source of pollution for water, sediment and fish in rivers that drain the Andean ranges. Some species, such as *Prochilodus lineatus*, have levels of toxins that exceed guidelines for safe human consumption (Colombo *et al.,* 2000).

40.5 FISHERIES MANAGEMENT

Regional management strategies

Freshwater fishery management is not considered an important issue in the La Plata Basin. In Brazil the main purpose of management programmes is to increase fishery yield through stocking of exotic and native species and control of the fishery (Agostinho and Gomes, 1997). In the Lower Paraguay and Paraná basins, few sporadic programmes directed to control conflicts among resource stakeholders were established. These largely failed due to lack of funding and fisheries legislation (Quirós, Bechara and de Resende, 2007). Generally, management regulations are difficult to apply due to the widely distributed nature of fishers and fisheries.

Licensing, equipment, mesh-size restrictions, length limits and closed seasons are used to control fisheries in the Paraná Basin, Paraguay River and the Pantanal. Both commercial and recreational fisheries are required to have licences which are provided by the Ministry of Agriculture. Equipment and mesh sizes are regulated and the ministry governs the use of specific gear in certain areas of the fishery. For instance, in the Paraná, gillnets have size restriction of 120 mm, trammel nets 70 mm and cast nets 80 mm. Regulations on area and season restrictions are published annually; for the year 2000, fisheries using nets and longlines were forbidden for four months (Quirós, Bechara and de Resende, 2007). Despite the strict regulations on fishing, poaching, illegal fishing and the use of illegal gear are common (Quirós, Bechara and de Resende, 2007).

Transboundary management

La Plata Basin countries established the Intergovernmental Coordinating Committee (CIC) as a coordinating mechanism for the basin. The La Plata Treaty was agreed upon in 1969 to ensure shared management of water resources. Through the CIC various management initiatives to ensure cooperation have been carried out including the Framework for the Sustainable Management of Water Resources of the La Plata Basin; however, all initiatives lack fishery management measures.

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41 GREAT LAKES BASIN

41.1 OVERVIEW

The Great Lakes comprise Lakes Superior, Michigan, Huron, Erie and Ontario (Table 41-1). With a surface area of 244 180 km² these lakes form the largest group of freshwater lakes in the world and contain approximately one-fifth of the world's freshwater (Abell *et al.,* 2000). Except for Lake Michigan, the lakes provide a natural border between Canada and the United States. Individually, the lakes rank among the 14 largest in the world. The largest, deepest and coldest, Lake Superior, covers 82 100 km² and is the second largest freshwater lake in the world, with a volume of 2 900 m³. The second largest is Lake Huron, which is the fourth largest lake in the world covering 59 600 km² with a volume of 850 m³. Lake Michigan is the fifth largest lake in the world covering 57 800 km² with a volume of 1 180 m³ and is entirely within the United States. Lakes Erie and Ontario are the eleventh and fourteenth largest lakes in the world, respectively, covering 25 670 km² and 19 010 km², respectively (EPA, 2016). Numerous small rivers and streams feed into the lakes; among the large rivers feeding Lake Superior are the St Louis and Pigeon. Other major rivers that feed the lakes are the Spanish and French Rivers (Lake Huron), the Thames and Detroit Rivers (Lake Erie) and the Niagara River (Lake Ontario). Lake Ontario receives the entire outflow of the other four Great Lakes, which travels through the Gulf of St. Lawrence into the Atlantic Ocean (Abell *et al.,* 2000).

Table 41-1. Characteristics of the Laurentian Great Lakes

Lake	Country	Area of the lakes (km²)	Percent area of the lakes in countries	Total population of the lake basin	Population density/km²
Superior	Canada	82 100	35.0		
	United States		65.0		
Huron	Canada	59 600	60.4		
	United States		39.6		
Erie	Canada	25 670	60.4		
	United States		39.6		
Ontario	Canada	19 010	52.7		
	United States		47.3		
Michigan	United States	57 800	100		
Total		**244 160**		**3 611 095**	**9.8**

Fish diversity

According to FishBase, the Great Lakes contain 140 species, of which 14 are introduced and three are endemic (FishBase, 2017). The freshwater fish of the Great Lakes tend to be adapted to one of two habitat types, lacustrine (lake) or lotic (river and stream) (Underhill, 1986). Endemic species consist of orange-spotted sunfish (*Lepomis humilis*), starhead topminnow (*Fundulus dispar*) and orange throat darter (*Etheostoma spectabile*) (FishBase, 2017). A subspecies of walleye, known as blue pike, was once endemic to Lakes Erie and Ontario but is now considered extinct (Abell *et al.,* 2000). Human pressure during the last two centuries has led to the local extinction of 18 native species; currently 61 fish species in the Great Lakes are considered threatened or endangered (GLFC, 2017a,b).

Fish introductions

According to the Environmental Protection Agency, at least 25 invasive fish species have entered the Great Lakes since the 1800s. These include the round goby (*Neogobius melanostomus*), sea lamprey (*Petromyzon marinus*), Eurasian ruffe (*Gymnocephalus cernua*), alewife (*Alosa pseudoharengus*) and common carp (*Cyprinus carpio*) (EPA, 2016). Many species were introduced to the lake for sport and recreational purposes, including cutthroat, rainbow and sea trout (*Oncorhynchus clarkia, O. mykiss* and

Salmo trutta), pink, chum, coho, sockeye, Chinook and Atlantic salmon (*O. gorbuscha, O. keta, O. kisutch, O. nerka, O. tshawytscha* and *Salmo salar*) and Arctic char (*Salvelinus alpinus*) (FishBase, 2017).

41.2 FISHERIES OVERVIEW

The Great Lakes sustain commercial, recreational and indigenous fisheries. Commercial fishing, once the primary industry on the lakes, has generally declined due to the collapse of desirable species. A small amount of commercial fishing is still carried out, mainly for whitefish species. Commercial fishery operations vary from state to state, and every lake has an indigenous component of the commercial fishery except for Lake Erie. Emphasis on the fishery has switched to sport fishing, based on coho and Chinook salmon, lake trout, walleye, rainbow trout and Arctic char (Kinnunen, 2003). For indigenous fishers fishing is a way of life passed down from generation to generation. Indigenous fisheries are regulated by the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) which works to ensure the treaty's reserved rights (established by Native Americans and the United States Government between the 1830s and 1850s) of indigenous populations are maintained. Indigenous fishers are allowed to fish both commercially and for subsistence. Most of the fishery comprises small boats and the focus is on whitefish, lake trout, lake herring and salmon which constitute 95 percent of the indigenous commercial harvest, and are culturally and nutritionally important sources of food (GLIFWC, 2017).

Fishing methods

For the commercial fishery, various types of gear are used on the Great Lakes. In the American waters, trap nets, gillnets and hoop nets are used to catch commercially important species. Trawl fishing is also carried out but on a small scale, and mainly for whitefish. In the Canadian waters, hoop nets and gillnets are used to catch all commercial species in Lake Ontario and for lake whitefish, lake trout, walleye, perch and bass (Kinnunen, 2003). Indigenous fishing mainly consists of gillnet fishing from large tugs or small boats; some fishers also use trap nets. Ice fishing with nets is carried out in the winter months (GLIFWC, 2017).

Fish trade

The American commercial fisheries on Lake Ontario were worth USD 65 671 in 2009. Lake Superior commercial fisheries in America were worth USD 4 904 422 in 2009. The Lake Huron 2009 harvest was valued at USD 4 880 630, the Lake Erie 2009 fishery was worth USD 5 396 398 and Lake Michigan's fishery was valued at USD9 947 692 (GLMRIS, 2012). Likewise, Canadian fisheries harvest on Lake Huron in 2014 was valued at CAD 4 678 668, Lake Superior CAD 675 300, Lake Ontario CAD 510 477 and Lake Erie CAD 27 542 689 (OCFA, 2017). Recreational anglers fishing in the Canadian Great Lakes spent CAD 215 million on recreational fishing expenditure that included transportation costs, food and lodging. Anglers invested CAD 415 million in boats, outboard motors and fishing gear (Fisheries and Oceans Canada, 2008). Similarly, in the United States Great Lakes recreational anglers generated USD 2.9 billion in expenditure in 2011, with an economic multiplier effect of USD 7.2 billion (ASA, 2013); conversely, the commercial fishery contributes less than 1 percent of that amount (NOAA, 2012).

Employment

Table 41-2 indicates the participation in commercial and recreational fisheries within the Great Lakes Basin. There was no information regarding employment in commercial fisheries in either country. In Canada, there were 364 467 recreational anglers in 2005, of which 77 percent was residents. Male anglers made up 78 percent of resident anglers and 87 percent of non-resident anglers (Fisheries and Oceans Canada, 2008). In the United States, there were 1.6 million recreational anglers in 2011. Lake Erie attracted 38 percent of them and fishers averaged 13 days of fishing annually. Although more men than women fished in 2011, the total number of women fishing across the United States increased to 8.9 million. The participation rate in recreational fisheries correlated with household income (U.S. Department of the Interior, Fish and Wildlife Service and U.S. Department of Commerce, U.S. Census

Bureau, 2011). Secondary services of recreational fishing in the United States also provided jobs for roughly 50 000 people (ASA, 2013).

Table 41-2. Participation in Great Lakes fisheries activities

Lake	Recreational fishers	
	USA	Canada
Lake Superior	147 000	32 667
Lake Michigan	413 000	
Lake Huron	262 000[1]	162 121
Lake Erie	639 000[2]	73 161
Lake Ontario	143 000[3]	96 518
Total	**1 604 000**	**364 467**

Note: The Canada recreational fisheries total includes both resident and non-resident anglers for 2005; U.S. Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau, (2011).

[1] Also includes recreational anglers from St Mary's River.
[2] Also includes anglers fishing the Detroit River.
[3] Also include anglers fishing the Niagara River.
Source: Fisheries and Oceans Canada, 2008.

Estimated fisheries production

Table 41-3 indicates the commercial fishery catches for each of the Great Lakes from various literature sources. In Lake Ontario no indigenous commercial catches are reported in Table 41-3. The commercial catch was made up of yellow perch (99 percent), and cisco (lake herring) (1 percent) (NOAA, 2019). In Canadian waters, most catches from Lake Ontario consisted of yellow perch, sunfish and lake whitefish, of which the lake whitefish catch has declined 29 percent since 2016 (OCFA, 2019).

Fish catches from American waters of Lake Superior contribute 8 percent to the total fish harvest from the Great Lakes and contribute 15.8 percent of the value of the fishery (the direct value of the Great Lakes commercial fishery in the United States was USD 16.36 million in 2017) (NOEP,2020). Fish catches from Table 41-3 include commercial figures from seven indigenous fishing communities that reported catches to the GLIFWC. In the Canadian portion of the lake, cisco (lake herring) accounted for 53 percent of the catch and lake whitefish 42 percent of the catch (OCFA, 2019).

American catches from Lake Huron declined since 1989, from peak harvest levels in the 1990s (2 404 tonnes) to 872 tonnes in 2009 (NOAA, 2019). Lake whitefish constituted that largest proportion of the catch (63.3 percent). Fish catches from Table 41-3 also include indigenous catches from the Chippewa Ottawa Resource Authority (CORA) member tribes and Michigan licensed commercial fishers. Canadian catches have largely declined from an average yearly catch of 2 722 tonnes pre2000 to 1 779 tonnes (average) post2000. There has also been a decline in the total number of species caught (the 1994 catch consisted of 16 species and in 2014 the catch comprised nine species) (OCFA, 2019).

Catches from the American waters of Lake Erie have declined from historical averages but represent the largest catch from the American portion of the lake. Catches from the lake contribute 11.5 percent to the total Great Lakes harvest. Most of the harvest consists of perch species, (yellow and white perch, 51.4 percent). Canadian catches on Lake Erie have been largely stable since 2000, with catches ranging from 8 678 tonnes to 12 405 tonnes, with most of the catch comprising rainbow smelt, walleye and yellow perch (OCFA, 2019). The Canadian Lake Erie fishery is the most valuable, with the commercial fishery valued at CAD 43.04 million in 2017 (OCFA, 2019), constituting 59 percent of fish production from the Laurentian Great Lakes.

Lake Michigan fish catches only come from the United States and contribute 11.5 percent to the total commercial harvest from the lakes. Indigenous fishers from Illinois, Indiana and Michigan as well as CORA member tribes are included in the figures in Table 41-3. As with all the other Great Lakes, whitefish is the main target of commercial fishers (80 percent), catches of which have declined due to overfishing.

Two indigenous groups do not report catches to the Great Lakes and Mississippi River Interbasin Study (GLMRIS), but established the Great Lakes Indian Fish and Wildlife Commission (GLIFWC). The 2014 commercial indigenous fishery in the 1842-treaty-ceded waters of Michigan on Lake Superior consisted of ten large and ten small boat fleets that harvested 318 tonnes, mainly consisting of whitefish and lake trout (Mattes, 2016).

Table 41-3. Commercial fishery production estimates for the Great Lakes

Lake		Catch estimate (tonnes)	Year	Reference
Lake Superior	United States	1 233	2017	NOAA (2019)
	Canada	295	2017	OCFA (2019)
	Indigenous	316	2014	Mattes (2016)
Lake Michigan	United States	1 544	2017	NOAA (2019)
Lake Huron	United States	872	2017	NOAA (2019)
	Canada	1 148	2017	OCFA (2019)
Lake Erie	United States	2 190	2017	NOAA (2019)
	Canada	11 232[1]	2017	OCFA (2019)
Lake Ontario	United States	31	2017	NOAA (2019)
	Canada	222	2017	OCFA (2019)
Total		**19 083**		

[1]Also includes catches from Lake St Clair.

Status of the fisheries: catch trends

Generally, fisheries harvests have decreased for all lakes since fisheries data were first published in 1989. Catches in the American waters of Lake Ontario decreased between 2000 and 2009 from 32 tonnes to 19 tonnes, due to a decrease in the harvest of numerous species such as white bass, rock bass, black crappie and sunfish. There was an increase in fish catches in Lake Superior post-1996, due to the inclusion of commercial catches from indigenous fisheries in 1996, and again in 2000 after the inclusion of commercial data from Lake Superior fisheries in Minnesota.

The fishery on Lake Michigan experienced a rapid decline in the 1990s. Peak catches of 8 130 tonnes in 1992 steadily declined until 1999 and then suddenly dropped to 3 156 tonnes in 2000. Similarly, the decline in catches in Lake Huron is partly due to decrease in the harvest of rainbow smelt, sucker and perch species and catfish (GLMRIS, 2012).

Aquaculture

Fish farming is a growing industry within the Great Lakes Basin. Only lake-based cage culture is allowed on the lakes, which began in the 1980s and occurs only in Georgian Bay in Lake Huron. At present, Canada licenses six aquaculture operations at seven facilities, with a further three operations conducted by the First Nations, which are not licensed. Rainbow trout is the dominant species produced in Canadian aquaculture systems, with an estimated production of 8 000 tonnes annually, which represents 75 percent of production (Anderson *et al.,* 2015). Fish stocking also occurs within the Great Lakes; lake trout stocking programmes on Lakes Huron and Superior have been conducted to rehabilitate populations of lake trout particularly affected by commercial fishing and sea lamprey introduction. Other species that are stocked for recreational and commercial purposes are salmon species, trout species, bass, walleye and yellow perch (FWS/GLFC, 2010).

Recreational fishing

Table 41-4 indicates the estimated number of fish retained by recreational anglers in Canada (no figures were available for the United States). In Canada, recreational anglers caught an estimated 23.6 million fish in 2005 and retained close to 7.1 million fish. The top five species caught have not changed significantly over the last ten years. Perch constituted 30 percent of the fish caught in the Great Lakes regions, followed by smallmouth bass, sunfish, walleye and rock bass. Resident anglers caught over 82 percent of the total harvest, while non-resident anglers caught 17 percent (Fisheries and Oceans Canada, 2008). Recreational fishers in the United States fished 19 661 000 days in 2006 and the most commonly targeted species were black bass, northern pike, perch and salmon (U.S. Department of the Interior, Fish and Wildlife Service, U.S. Department of Commerce and U.S. Census Bureau, 2006). In the United States there are comprehensive marine recreational fisheries data, but there are no national-scale inland recreational fish data (Cooke and Murchie, 2013).

Table 41-4. Recreational fishery production estimates (number of fish) for the Great Lakes

Lake/country		Fish retained (n)	Year	Reference
Lake Superior	Canada	387 397	2005	Fisheries and Oceans Canada (2008)
Lake Huron		1 442 319		
Lake Erie		2 362 208		
Lake Ontario		1 059 013		
Total		**5 250 937**		

41.3 THREATS TO THE FISHERIES

Climate change

Mean annual temperature across the basin is expected to increase 2 °C to 3 °C by 2050, with greater seasonal changes, such as an increase in summer and winter temperatures by 7 °C to 8 °C, respectively (Winkler, Arrit and Pryor 2012). Lake water temperature is also expected to increase from 1.5 °C to 3.4 °C across the basin, which would lead to early breakup of ice and early onset of summer stratification which could lead to reduced fish recruitment (Jensen *et al.,* 2007). Lake Michigan could be ice free as early as 2020 (Hayhoe *et al.,* 2010). Prediction of lake level changes are varied and range from a decline of around 1.5 m to an increase of 1 m (Angel and Kunkel, 2010). Average annual runoff is expected to increase by 7 percent to 9 percent. There will be reduced habitat for cold water fish species (Cline, Bennington and Kitchell 2013) and change in ice cover could affect winter mixing, impacting fish communities that rely on mixing for delivery of oxygen and food to deeper parts of the lake (Jensen *et al.,* 2007).

Invasive species

Sea lamprey is described as the most detrimental exotic species that has had an enormous negative impact on the Great Lakes fishery. Sea lampreys attach to fish and rasp through fish scales and skin to feed on the host's body fluids; they prey on most species of large Great Lake fish such as trout, sturgeon, whitefish, ciscoes and walleye. First recorded in Lake Ontario in 1835, sea lamprey populations exploded in the Great Lakes between the 1920s and late 1930s. Sea lampreys have decimated the Great Lake fishery. Before the sea lamprey invasion, Canada and the United States harvested about 7 000 tonnes of lake trout in the Upper Great Lakes annually. By the early 1960s, the catch had dropped to 136 tonnes, about 2 percent of the previous amount. During this time, 85 percent of fish that were not killed by lamprey had lamprey attack wounds (GLFC, 2017a,b). More than 180 non-native species have entered the Great Lakes, with most entering the lakes via the ballast water of ships (National Wildlife Federation, 2019).

Water quality

Plastic pollution in some parts of the Great Lakes is higher than any other waterbody in North America. Lake Erie is the most densely populated of the Great Lakes and microplastic pollution was as high as 466 305 parts per kilometre; as water flows from one lake to the next, plastic accumulates in Lake Erie. The exact impact of these plastics on aquatic ecosystems is unquantified (Eriksen *et al.,* 2013). Decades of industrial and agricultural discharges into the lakes in general led to severe pollution of the lake in the 1950s; pollution levels were so high that areas of Lake Erie were declared dead zones. Since the 1970s, a major effort to control pollution has led to improved water quality. But sediment contaminated with heavy metals and toxins still poses a threat to human health, as fish from certain areas of the lakes are unsafe to eat (EPA, 2016). Additionally, in 2014 water quality problems in Lake Erie led to a toxic algal bloom that shut down water supplies for half a million people in Toledo, indicating water quality is an ongoing problem (Circle of Blue, 2015).

41.4 FISHERIES MANAGEMENT

National management strategies

American states have their own state-governed fisheries management plans for the Great Lakes. For instance, the goal of the Fisheries Management Plan for Minnesota Waters of Lake Superior is to protect the Lake Superior ecosystem and rehabilitate and manage diverse self-sustaining fishery communities. Fisheries regulations in place are largely similar to those that govern other American waterways (licence required to fish, closed seasons, catch limits, gear restrictions and so forth). The overall aim of this plan is to improve water quality and other aquatic habitats, restore native fish stocks and prevent invasive species intrusion (Goldsworthy *et al.,* 2016). Because inland fisheries are managed at state/provincial levels, Cooke and Murchie (2013) identified the need to adopt coordinated, transjurisdictional management strategies for inland fisheries to ensure the sustainability of inland fisheries in North America.

Indigenous population relations

Indigenous people work with both American and Canadian governments in co-management of the Great Lakes. Regulation is key for effective management. Establishing closed seasons, closed areas and harvest limits and enforcing indigenous laws are used as part of self-regulation. Permits are required to fish and quotas for certain species are set by indigenous leaders. Biological assessments are carried out to monitor the commercial fishery and are compiled into annual commercial reports (GLIFWC, 2017).

Transboundary management

'The Joint Strategic Plan for Management of Great Lakes Fisheries' was first established in 1981 and revised in 1991. The strategic plan had a common goal to secure fish communities based on self-sustaining stocks, supplemented by hatchery stocks. From these communities, fishing opportunities could serve the needs of food, recreation, heritage, employment and healthy ecosystems as identified by society. There was consensus on three strategies for fishery management: (1) ecosystem management to identify environmental issues, draw up resolution strategies and promote procedures for preventing the introduction of invasive species; (2) information sharing and coordinating the development of standards for recording and maintaining data; (3) accountability in fishery agency, lake committee and fishery commission reports (GLFC, 2007).

The Great Lakes Fishery Commission in partnership with the U.S. Fish and Wildlife Service and Fisheries and Oceans Canada implemented the 'Sea Lamprey Control Programme', which has been successful in reducing sea lamprey populations by 90 percent in most areas of the Great Lakes. Lampricide TFM is used to target juvenile lamprey in their nursery tributaries; low-head barriers are also used to prevent adult lamprey from accessing tributaries to spawn in (these barriers do not block other fish species). Traps and pheromone cues are also used in the tributaries to catch adult lamprey or lure them to unsuitable spawning grounds or where they are easy to treat with lampricides (GLFC, 2017a,b).

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42 MISSISSIPPI RIVER

42.1 OVERVIEW

The Mississippi River is the largest river in North America. Its watershed includes parts of two Canadian provinces and parts of or all of 31 US states (Table 42-1). The Mississippi River flows 3 731 km from its headwaters in Lake Itasca in Minnesota to the Gulf of Mexico. The river is a major transportation corridor and has been greatly altered for navigation, agriculture, industry and urbanization purposes. It is divided into three sections: the Upper Mississippi River (UMR), from its source to the confluence with the Missouri River; the Middle Mississippi River (MMR) from the Missouri River to the confluence with the Ohio River; and the Lower Mississippi River (LMR) from the Ohio River to the delta. The daily discharge ranges from 3 568 m^3/s to 55 558 m^3/s with an average flow of 17 358 m^3/s. The Mississippi contains many tributaries but the four major confluences are the Arkansas, Illinois, Ohio and Missouri rivers. Fisheries habitats of the Mississippi are complex, with 44 different aquatic habitats described for the UMR alone (Wilcox, 1993). Undoubtedly, habitat diversity was greater before channelization and impoundment, but even in its current state the Mississippi provides a diverse range of habitats and seasonal water-level fluctuations (Schramm, 2004).

Table 42-1. Characteristics of the Mississippi River

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
United States	3 242 433	99	83 007 705	25.60
Canada	27 621	1	8 818	0.3
Total	**3 270 054**	**100**	**83 016 523**	**13**

Fish diversity

According to FishBase, the Mississippi River contains 230 species, most of which are from the families' Cyprinidae and Percidae (FishBase, 2017). The LMR is the second richest ecoregion in North America after the Tennessee River. The LMR contains a wide diversity of large river fish such as lamprey, sturgeon, American paddlefish and gars. Only 4 percent of species are endemic and are usually found in the tributary drainage areas (Abell *et al.,* 2000).

Fish introductions

There are seven recorded fish introductions according to FishBase: common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*H. noblis*) grass carp (*Ctenopharyngodon idella*), black carp (*Mylopharyngodon piceus*), goldfish (*Carassius auratus*) and sailfin catfish (*Pterygoplichthys disjunctivus*) (FishBase, 2017).

42.2 FISHERIES OVERVIEW

Commercial and recreational fishing are conducted on the Mississippi. Recreational fishing is hugely popular within the UMR, particularly in Minnesota. The Minnesota Department of Natural Resources frequently conducts creel surveys on portions of the river and river lakes. Common recreational fish species caught in the region are the northern pike, channel catfish, smallmouth bass, white crappie, black crappie and walleye. Recreational fishery has not been measured in the MMR or LMR reaches. Observations from the LMR suggest that freshwater catch rates are high, but fishing effort and thus harvest rates are low. Its large size and dangerous currents, the presence of large commercial craft and lack of public access have largely discouraged recreational fishing. Access to the river is generally difficult owing to the large annual changes in river level and separation of floodplain lakes (Schramm, 2004). There is no commercial fishing in the headwaters of the UMR. In the MMR commercial catch consists of bigmouth, smallmouth and black buffalo fish (27 percent); silver and bighead carp (21 percent); common carp (17 percent); and blue, channel and flathead catfish (15 percent) (GLMRIS, 2012). In the Ohio River, the catch constitutes paddlefish, mooneye, shad and carp (41.2 percent), bullhead, channel flathead and blue catfish (38.1 percent), buffalo suckers and carpsuckers (15 percent) and sturgeon (1.6 percent) (GLMRIS, 2012).

Fishing methods

The commercial fishing sector uses many of the same types of fishing gear used in the marine sector, but at a much smaller scale. Generally, the predominant methods are trawls, gillnets, weirs, traps and hook and line (FAO, 2005). For recreational fishing, regulations on permissible gear can vary from state to state. For instance, in Missouri, fish can be caught using hook and line, trotline, throwline, bank line and limb line. Only live bait traps are allowed in Missouri and the maximum number of hooks that can be used at any one time in the Mississippi River by an individual is 50; there is no restriction on the number of poles (any more than two and the poles must be labelled). The use of explosives, poison, chemicals or electric equipment to kill or stun fish is illegal as is attempting to take fish by hand (MDC, 2017).

Fish trade

Commercial harvest in the UMR is likely driven more by the selling price and market demand than catch rate. In the UMR and Ohio River commercial fisheries value between 1992 and 2005 averaged USD 4 441 222 and USD 1 836 161 (GLMRIS, 2012). In the LMR, freshwater fisheries harvest in Louisiana is valued at approximately USD3 147 000 (IEC, 2004). Most of the fish harvest is marketed fresh or frozen for human consumption (FAO, 2005).

Employment

Throughout the LMR, more than 4 850 people are employed in the commercial fishing sector. Most (4 500) are employed in Louisiana, while about 350 are employed in Mississippi; employment in other states would appear to be minor (IEC, 2004). Estimates of employment in commercial fisheries in the UMR states were unavailable, but are expected to be similar to the LMR. Recreational fishing is a hugely popular pastime in the United States, with an estimated 44 million recreational anglers nationwide (FAO, 2005) – this also includes fishers in marine waters. Estimates of recreational angler participation is difficult to assess, with angling surveys and tournaments only featuring a small section of river. In the Upper Arkansas River in the UMR, in 2012 100 563 anglers fished the river between Leadville and Parkdale (Policky, 2015), however, this is not representative of the whole river. Similarly, in Minnesota a reported 1 285 anglers participated in a creel survey on the Mississippi River (Altena, 2008), which is also likely to be an underestimation of the actual figures.

Estimated fisheries production

Table 42-2 indicates the estimated commercial fisheries production from the Mississippi River and its major tributaries. Generally, there are few comprehensive inland fishery statistics on a national scale. Freshwater fishing data for the Mississippi states are scattered and inconsistent (IEC, 2004), as there are disparities in reporting systems and each state has its own state agency responsible for freshwater fisheries. For instance, in Illinois, Kentucky, Tennessee and Arkansas the total reported freshwater catch on the Mississippi River is broken down by species, whereas Missouri only reports the total catch and Mississippi does not report freshwater commercial catches at all (IEC, 2004). Despite this, fishing effort, catch rate, harvest rate and mean size of fish have remained relatively constant, or trended upwards over the last 20 years.

The UMR Basin harvest level for 2005 was 4 559 tonnes. Catch statistics for the UMR were first published in 1989 and have fluctuated from a high of 7 290 tonnes in 1990 to a low of 4 099 tonnes in 2000. In the Ohio River fish catches for 2005 were 678 tonnes and fluctuated between 748 tonnes and 417 tonnes in 2003-2004 (GLMRIS, 2012). Reduced harvest levels in 2003 can be attributed to the decrease in harvests of species in Kentucky's waters (the Kentucky and Ohio Rivers), due to the decrease in fishing days caused by long periods of high water and flow (GLMRIS, 2012).

Table 42-2. Commercial fishery production estimates for the Mississippi River

River	Catch estimate (tonnes)	Year	Reference
Upper Mississippi River[1]	4 559	2005	GLMRIS (2012)
Ohio River[2]	678	2005	GLMRIS (2012)
Lower Mississippi River[3]	3 751	n/a	IEC (2004)
Total	**8 988**		

[1]Catches from the UMR consist of fish caught in the UMR, Illinois, Kaskaskia and Rock rivers.

[2]Catches from the Ohio River consist of fish caught in the Ohio, Wabash, Cumberland and Kentucky rivers.

[3]Consists of fisheries harvests from the Mississippi River in Louisiana only.

Status of the fisheries: catch trends

Catches generally declined 13.3 percent from 1989 to 2005. Catch levels have fluctuated due to a decrease in harvest levels of various species. Harvest levels of common carp were down 35 percent between 2000 and 2005 compared to historic averages, harvests of buffalo, catfish and bullheads have also declined by 8 percent. However, harvests of other species have increased, such as the shovelnose sturgeon (+60 percent), silver carp and bighead carp (+200 percent) and grass carp (+78 percent) (GLMRIS, 2012).

Aquaculture

Most states along the Mississippi River privately own fish hatcheries to manage sport-fishing populations. Fish are stocked for a number of reasons. The most common are to establish sport fish populations in new or renovated areas; restore fish populations following natural or human fish kills; introduce new species to the fishery; enhance year Class strength and recruitment of existing species; and enhance harvest potential (MSDWP, 2017). Most hatcheries are dedicated to trout production that are introduced into streams to supplement natural trout populations in heavily fished streams. Other species that are produced in hatcheries include crappie, striped bass, walleye, striped and channel catfish, bluegill, paddlefish and smallmouth bass (TWRA, 2017; MSDWP, 2017).

Recreational fishing

In the UMR in Minnesota a creel survey was conducted from May to September 2007 covering 45 miles between St Cloud Dam and Coon Rapids Dam on the Mississippi River; 1 285 anglers caught 80 650 fish. The numbers of fishers angling from the riverbank and those fishing from a boat were fairly even (47.5 percent and 52.5 percent, respectively). Twelve fish species were represented in the catch, of which smallmouth bass accounted for 51 percent, followed by walleye and channel catfish. Of the total catch, 6 198 were harvested; channel catfish were harvested in the greatest numbers accounting for 34.9 percent of the total harvest, followed by smallmouth bass (22.4 percent). Estimated total season fishing pressure was 118 469 hours or 24.1 angler hours per acre (Altena, 2008).

42.3 THREATS TO THE FISHERIES

Climate change

Delta systems are recognized for being highly sensitive to sea-level rise and rates of sea-level rise can exceed the global average in heavily populated delta areas due to subsidence, particularly in the Mississippi River Delta (IPCC, 2007). Hurricane Katrina, although not attributable to climate change, illustrates the consequences to ecosystems services if such events intensify in the future. Hurricane Katrina caused the loss of 388 km^2 of coastal wetlands, levees and islands within the delta (Barras, 2006). Climate change will likely impact wetlands within the delta, as subsidence is increasing by 10 mm/year to 15 mm/year (Dixon *et al.,* 2006).

Water quality

The Mississippi River flows through an area of intensive agriculture and urban areas. As such, the river has become a sink for fertilizers, pesticides and domestic and industrial wastes. During the 1940s to 1960s the river and its aquatic life were severely impacted by pollution. Improved wastewater treatment has reduced pollutants in the Mississippi River, but persistent toxins still remain in the sediments (Sullivan *et al.,* 2002). Fish within the Mississippi River are generally safe for human consumption, however fish consumption guidelines advise against consumption of fish from some areas due to suspected mercury contamination. Fish health remains impacted by various contaminants, particularly bio-accumulative organic compounds (Schmitt, 2002). Organochloride contaminant (DDT and PCBs) concentrations in fish were high in the industrialized and urbanized areas of the Ohio and Mississippi rivers. Heavy metal pollution concentrations of selenium and mercury were high in fish from the Mississippi River at Memphis. Additionally, biomarker results indicated that 73 percent of smallmouth bass analysed by Schmitt (2002) from the Mississippi River at Lake City were intersex indicating exposure to endocrine-disrupting chemicals.

Habitat modifications

The Mississippi River has undergone significant alterations from channelization, flood proofing and impoundment. In the MMR, levees have reduced the active floodplain (the portion inundated by spring floods) by 50 percent (Duyvejonck, 2002). Throughout the LMR levees have separated the connection of the river from 90 percent of its historic (103 000 km^2) floodplain. Also, the bypass of 16 meanders in the river during the 1940s shortened the river by 245 km and increased the slope of the river, leading to lower summer and autumn water levels. Throughout the UMR, dams have increased the area of aquatic habitat at low water from 971 km^2 to 1 495 km^2, permanently inundating 23 percent of historic wetlands and seasonal floodplains (Schramm, 2004). Habitat alteration for navigation has directly affected fish populations. Entrainment of larval and juvenile fishes by towboats is significant (Bartell and Campbell, 2000). Estimated recruitment losses in the UMR from a 25 percent increase in boat traffic ranged from 1 420 walleye to 88 million emerald shiner (Schramm, 2004).

42.4 FISHERIES MANAGEMENT

The individual states within the Mississippi Watershed manage the recreational and commercial fisheries. Federal involvement is limited to research, protection of endangered and threatened species, and coordination. There is also no standard system of statistics for fish landings among the Mississippi states (FAO, 2005).

State fisheries management and regulations

All states have their own set fishing regulations, which are mostly similar; for instance, all states require a fishing licence for commercial and recreational fishing to fish the waters of the state individuals are resident in. In Missouri fishing regulations address allowable fishing methods; the allowable number of hooks; illegal fishing methods; area restrictions for specific species; daily catch limits; catch and release fishing; and length limits. Fish that are on state endangered or threatened lists cannot be harvested, and commercial fishers cannot take shovelnose catfish from the entire Missouri–Mississippi River (MDC, 2017).

Multistate management plans

The Lower Mississippi River Conservation Committee consisting of a coalition of 12 states and five federal partners, aims to restore aquatic resources within the river's active floodplain from the confluence of the Mississippi and Ohio Rivers to the Gulf of Mexico. The project was initiated in 2006 and to date most work conducted has been on the creation and rehabilitation of secondary channels. The aims of the project are:

- Maintain or improve aquatic habitat quantity, quality and diversity in the LMR ecosystem;
- Improve water quality by implementing a Clean Water Act;

- Restore, conserve and manage the biological diversity of native fishes, and provide for sustainable harvest of selected fish species;
- Increase public use and awareness of fisheries resources in the LMR ecosystem; and
- Ensure coordinated management of the LMR ecosystem through the involvement of management agencies (LMRCC, 2015).

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43 YUKON RIVER

43.1 OVERVIEW

At 3 200 km in length, the Yukon River is the tenth longest river in the world and fourth longest in North America (Table 43-1). The Yukon River originates in the Coastal Range mountains of British Columbia, flows northwest through the Yukon Territory and into Alaska, and empties into the Bering Sea. The river has dozens of tributaries and distributaries. In Alaska the main tributaries are the Porcupine, Tanana and Koyukuk rivers; in Canada the principal tributaries are the Teslin, Pelly and White rivers (Abell *et al.,* 2000; Loring and Gerlach, 2010). The Yukon has a low gradient with few rapids except for those at Miles Canyon (Canada). It is a slow-flowing, shallow river, except during spring melt runoff. The Yukon River Basin can be divided into two regions: upstream of the confluence with the Porcupine River and the remaining 1 600 km to the Bering Sea (Abell *et al.,* 2000).

Table 43-1. Characteristics of the Yukon River

Country	Area of the basin (km²)	Percent area of the river in countries	Population of the river basin	Population density/km²
United States	516 200	61	4 624	0.009
Canada	323 800	39	2 205	0.007
Total	**840 000**	**100**	**6 829**	**0.008**

Fish diversity

According to FishBase the Yukon River contains 26 species, of which 13 are salmonids and there are no known endemic species (FishBase, 2017). Five of the salmonid species are Alaskan, broad, humpback, pygmy and round whitefish. The Yukon provides migratory habitats for both Pacific and Arctic lamprey (*Entosphenus tridentatus* and *Lethenteron camtschaticum*). Chinook salmon (*O. tshawytscha*) and pink salmon (*O. gorbuscha*) also inhabit the waters of the Yukon.

Fish introductions

The only documented introduced species into the Yukon River is rainbow trout (*O. mykiss*). Population introductions were attempted in the Klondike River, and as of 2012, the distribution of rainbow trout in the Upper Yukon River Basin has been limited to below Whitehorse Rapids Dam, McIntyre Creek and Croucher Creek (von Finster, 2013).

43.2 FISHERIES OVERVIEW

The Yukon River supports commercial, recreational angling, domestic and indigenous food fisheries. Most of the fisheries' emphasis is on salmon, indeed for the Yukon First Nations, the importance of salmon is reflected in their lifestyles and 'first fish' ceremonies to celebrate the arrival of the yearly salmon run. Commercial fisheries for salmon in the Yukon drainage system began in the early 1900s and were established on the Alsek and Yukon rivers in Alaska, but only the Yukon River in Canada. Presently, the salmon industry is considered one of the most important industries and underpins a traditional subsistence lifestyle. Fisheries for chum salmon occur in coastal areas and along the entire length of the main-stem of the river and many of the tributaries; they are important subsistence and commercial species, but harvest by recreational anglers has so far been minimal. Recreational fishers mainly target salmon, northern pike (*Esox lucius*), inconnu (sheefish, *Stenodus leucichthys*), Arctic grayling (*Thymallus arcticus*), Dolly Varden (*Salvelinus malma)* and lake trout (*S. namaycush*) which are all widely dispersed throughout the basin. Commercial fishing for autumn-run chum salmon is based on in-season assessment of run size and is managed to allow harvest of surplus fish that exceed those needed for spawning, subsistence and indigenous fishing (Bue *et al.,* 2009).

Fishing methods

The fisheries of the Alaskan and Canadian Yukon use a variety of gear, including gillnets, dip nets, beach seines and fish wheels according to specific management that can change over the course of a season. In the Alaskan commercial fishery, dip nets account for most of the summer chum salmon harvest. At the start of the fishing season in the Lower Yukon, fishing for chum salmon with dip nets and beach seines is allowed, but any incidentally caught Chinook salmon must be released immediately. The use of gillnets is not allowed until in-season assessments indicate that most of the Chinook salmon have run. Gillnets with 6-inch or smaller mesh sizes are allowed to reduce the harvest of larger individuals. In the subsistence fishery, the use of 4-inch meshed gillnets is allowed for the harvest of non-salmon species such as sheefish, whitefish and northern pike (ADFG, 2017).

Fish trade

In the Canadian Yukon Territory, commercial fishing has declined substantially since the 1990s; the last estimate on economic value in 1986 suggested an estimated value of CAD 65 000 (DPA, 1998). In contrast, the economic value of the commercial salmon fishery in the Alaskan Yukon area in 2016 was estimated at USD1 972 371, with USD 2 million coming from the Lower Yukon (ADFG, 2017). The catch and commercial sale of Chinook salmon is prohibited, but anglers received USD54 800 from the sale of pink salmon. Most commercially harvested salmon from the Yukon River is either used as feed for sled dogs or is marketed fresh or frozen to local markets (Bue *et al.,* 2009). Recreational fishing on the Yukon River in the Canadian Yukon Territory is a CAD 23 million/year industry (DFO, 2007). Licence fees from recreational fishing bring an average CAD 250 000 annually to the Yukon Government's general revenue. Resident and non-resident anglers spend roughly CAD 12 million/year on fishing, and an additional CAD 11 million is spent on equipment such as boats and outboard motors. Combined, the average annual expenditure per angler is CAD 1 690 (Environment Yukon, 2010).

Employment

Participation in Yukon River commercial, recreational and subsistence fishing is outlined in Table 43-2; no values were obtained for participation in First Nations fisheries. Canadian commercial fisheries operations are small and limited to six waterways, therefore participation is low with 14 commercial fishing licences issued in 2008. Similarly, the subsistence fishery is small and licences are limited to individuals who primarily live off the land in remote or isolated areas. Recreational fishing constitutes the largest involvement in fisheries in the Canadian Yukon, with 12 748 recreational anglers in 2005, of which 21 percent was women (Environment Yukon, 2010).

Over the last two decades, there has been a steady decline in the number of recreational licences sold, and the average age of anglers has increased by eight years (Environment Yukon, 2010). There is a larger emphasis on commercial fishing within the Alaskan Yukon River Basin, therefore the participation in the fishery is higher than in Canadian waters. Recreational fishing is a popular pastime, but the figure in Table 43-2 is likely an overestimation as it includes anglers from the whole Alaskan region.

Table 43-2. Participation in Yukon River fisheries activities

Country	Commercial fishers	Subsistence fishers	Recreational fishers
United States	871[1]	2 737[2]	121 942[1,3]
Canada	14[1]	10[1]	8 401
Total	**885**	**2 747**	**130 343**

[1] Number of fishing licences.
[2] Fishing households, not individuals.
[3] Includes sports fishers in the whole of Alaska.

Sources: Environment Yukon (2010); Fisheries and Oceans Canada (2015); ADFG (2017); JTC (2019).

Permits are not required for subsistence fishing throughout most of the Alaskan Yukon area, except around urban areas and other areas accessible by road. In urban areas, 280 subsistence permits were issued in 2018.

Estimated fisheries production

Table 43-3 indicates the estimated fisheries production for commercial, recreational, subsistence and indigenous fisheries of the Yukon River. Once Chinook salmon begin entering the Lower coastal Yukon River, commercial fishing activities are restricted to certain tributaries. The 2018 summer season commercial harvest in the Alaskan Yukon was the largest since 1989, with most of the catch coming from the Lower Yukon Area (77 percent) (ADFG, 2019). The 2018 commercial autumn season harvest of chum salmon was above the 2013 to 2017 average, but the autumn season coho salmon harvest was below the 2013 to 2017 average.

The total number (n) of salmon harvested for subsistence in 2018 in the Alaskan Yukon is shown in Table 43-3. Summer chum and autumn chum salmon were the most harvested species, accounting for 79 percent of the subsistence harvest with Chinook and coho salmon accounting for the rest (ADFG, 2019). The subsistence harvest in 2018 was 214 455 salmon, lower than the average harvest between 2013 and 2017 (ADFG, 2019). As permits are not required for subsistence fishing, the largest share of subsistence harvest is estimated from postseason survey results.

The commercial fishery in the Canadian Yukon River is restricted to six waterbodies with strict quotas and management of Yukon River fisheries. The primary target species for the commercial fishery are lake trout and lake whitefish. Currently, the commercial fishery represents about 5 percent of the Yukon-wide harvest; fishing is restricted to lake trout in four lakes and autumn whitefish in two major rivers (Environment Yukon, 2010). Additionally, the First Nations are not obliged to divulge harvest information, but they sometimes share records with the Yukon Government.

Table 43-3. Fishery production estimates for the Yukon River

Type of fishery		Fish catch (n)	Year	Reference
Commercial	United States (tonnes)	509	2018	JTC (2019)
	Canada (tonnes)	5	2008	Environment Yukon (2010)
Recreational fishing* (n)	United States (n)	4 742	2017	ADFG (2019)
	Canada (n)	119 897	2015	Fisheries and Oceans Canada (2015)
Subsistence	United States (n)	178 759	2018	JTC (2019)
	Canada (tonnes)	0.5	2008	Environment Yukon (2010)
First Nations fishery	Canada (n)	5 996	2018	JTC (2019)
Total (tonnes)		**514**		

*Sport fishing refers to the total number (n) of fish caught and kept, not by weight.

Note: The fish catch total only includes values by weight.

Status of the fisheries: catch trends

In the Alaskan Yukon, the Chinook salmon stocks have experienced a dramatic decline since 1998 and the cause remains largely unknown. For 11 consecutive years there was no commercial fishery for Chinook salmon in the Yukon and Tanana rivers, and in the Upper Yukon, commercial fishing was absent in one district due to the lack of a commercial buyer. The sale of Chinook salmon was also prohibited for nine consecutive years and only incidental catches of Chinook salmon caught by specific gear could be kept for subsistence purposes.

In Canada, prior to 1990 any Yukoner could obtain a commercial fishing licence and fish over 20 lakes, however declining lake trout populations led to a ban on commercial fishing on small lakes and lakes with vulnerable or depleted lake trout populations. The fishery decreased considerably after 1998, but continues to provide some commercial activities and commercial harvests have largely been stable since 2010.

Aquaculture

Yukon River aquaculture is characterized by stocking fish under licence in pothole lakes, growing them to commercial size and harvesting them for sale. There are currently 16 fish farm licences issued on 23 pothole lakes, and these lakes are closed systems with no native fish. In 2007, 900 kg of fish were harvested from three lakes within the basin. Tank farms and hatcheries within the basin also produce substantial amounts (about 30 000 kg) of dressed Arctic char and about a million eggs for local markets and export (Environment Yukon, 2010).

Recreational fishing

The estimated fish harvest from recreational fishing in the Yukon River is outlined in Table 43-3. Recreational fishing is primarily carried out on the tributaries of the Yukon, mainly the Anvik, Porcupine and Innoko rivers. Most fish in the Yukon are harvested through recreational fishing. Sport anglers primarily target Arctic grayling, northern pike and whitefish in the Alaskan Yukon, with salmon species constituting 4.6 percent of the sport fish catch. Sport fishing for Chinook salmon was closed in 2018 in the Yukon River drainage system but was allowed in the Tanana River for salmon larger than 20 inches (JTC, 2019).

In the Canadian Yukon, anglers primarily target lake trout, northern pike and Arctic grayling, and in the 2015 sport fishing survey these fish accounted for most of the fish caught and kept by anglers. Concerns over the sustainability of the catch and waste of fish in the burbot fishery led to an introduction of catch and possession limits, and mandatory reporting of fish catches (Fisheries and Oceans Canada, 2015).

43.3 THREATS TO THE FISHERIES

Climate change

Over the last several decades, winter and summer temperatures have increased, and are projected to keep on increasing. The total ice coverage in the Yukon shrank by 22 percent between 1958 and 2008. This could have a profound impact on the hydrology of the glacier-dominated basins. Increasing temperature is leading to permafrost thawing, whereby the distribution of permafrost is changing, which can lead to shifts in drainage patterns and water chemistry, which could also alter the timing of peak and minimum flows required for fish spawning. Annual precipitation is expected to increase 5 percent to 20 percent across the region and snowfall is expected to decrease; as a result, spring snowmelt will begin earlier and long-term snowmelt will begin to decrease (Environment Yukon, 2011).

Fishing pressure

Each year an estimated 60 000 fish are taken from the Yukon River, making harvest the biggest stressor for fish populations. Recreational angling is the largest fishery sector within the Yukon area and therefore is the largest contributor to increased fishing pressure. Although fishing pressure within the Yukon River Basin is considered widespread, overfishing could potentially impact the whitefish populations as witnessed in whitefish populations in many of the large lakes in North America. Also, many whitefish populations are subject to an unknown amount of fishing pressure outside the basin, and fisheries data outside the Yukon drainage area are limited. Also, recreational surveys indicate that more female than male fish are harvested, because females are more active predators in the summer as they feed to store energy to produce eggs. Furthermore, anglers prefer to target larger individuals that feed more aggressively in the summer (Environment Yukon, 2010).

43.4 FISHERIES MANAGEMENT

National management

In the Alaskan salmon fishery, catching Chinook salmon has been prohibited for the past 11 years, and the sale of incidentally caught Chinook salmon has been banned for the last five years. This action was to ensure that fishers would not target Chinook salmon during gillnet commercial landing periods and fishers could only keep the salmon for subsistence purposes (JTC, 2019). Alaskan and Canadian government fisheries require that any commercial, recreational and subsistence fishers have a licence that must be renewed every year.

Transboundary management

The development of fisheries management in the Yukon Territory is based on the fundamentals outlined in the Yukon Umbrella Final Agreement created in the 1980s. The aims of this agreement are to ensure the management of all fish and wildlife resources and their habitats and ensure equivalent participation of Yukon indigenous people with other Yukon residents in management processes. This involves identifying management problems by conducting annual monitoring and surveys through angler surveys and monitoring of commercial catches to gauge the health of fish populations. Management options to protect fisheries are regulations that limit gear types, size of allowable fish and catch, and possession quotas. Regulations do not necessarily limit the overall harvest or effort. Stricter regulations such as limited entry and harvest quotas are also used when needed. Fish regulations in the Yukon generally identify sustainable harvest levels while not limiting fishing opportunities. Canadian jurisdiction allows year-round open seasons except for closed areas used to protect migrating salmon. Control measures target harvest control, possession and size limits as well as gear restrictions (Environment Yukon, 2010).

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44 MURRAY–DARLING RIVER

44.1 OVERVIEW

The Murray and Darling rivers cross four Australian states and one territory, draining roughly 14 percent of Australia's landmass (Table 44-1). Most of the water in the basin comes from the southern and western side of the Great Dividing Range, flowing into Australia's three longest rivers, the Murray, Murrumbidgee and the Darling; there are also approximately 30 000 wetlands within the whole catchment. The sources of the Murray and Darling are the Australian Alps and the headwaters of the Great Dividing Range, respectively (MDBC, 2006). The Murray–Darling flows for 3 370 km (Australian Government, 2004). It is a vital source of water for the major cities of Adelaide and Canberra, but the region is more than 30 percent arid (WRI, 2003). The Murray–Darling Basin is considered the food bowl of Australia contributing 39 percent of the nation's agricultural production and accounting for 50 percent of the nation's agricultural irrigation water (MDBC, 2006). The Murray–Darling rivers have great variability in year-to-year flows and their ecology is driven by large floods covering extensive floodplains (MDBC, 2006).

Table 44-1. Characteristics of the Murray–Darling River Basin

Area of the river basin (km²)	Percent area of the river	Population of the river basin	Population density/km²
928 686	100	2 274 954	2

Fish diversity

According to FishBase there are 21 species in the Murray–Darling from 12 families, eight of which are endemic (FishBase, 2017). However, Lintermans (2007) stated that the Murray–Darling has between 26 and 44 native species (Humphries, King and Koehn, 1999; Koehn and Lintermans, 2012), of which 24 are threatened. The basin is known for its richness in Percichthyidae (temperate perch) as well as Galaxiidae (common galaxias). Despite the low number of endemic species (11 species), the Murray–Darling is home to flagship species such as the silver perch (*Bidyanus bidyanus*), Murray cod (*Maccullochella peelii*), golden perch (*Macquaria ambigua*) and freshwater catfish (*Tandanus tandanus*) (Lintermans, 2007), all of which are threatened and in rapid decline; Murray cod is classed as critically endangered by the IUCN (Wager, 1996).

Fish introductions

The Murray–Darling Basin contains at least 11 alien fish species, which currently make up approximately a quarter of the basin's total fish species. These include brown trout (*Salmo trutta*), Atlantic salmon (*Salmo salar*), brook trout (*Salvelinus fontinalis)*, rainbow trout (*Oncorhynchus mykiss*), carp (European carp, common carp and koi carp, *Cyprinus carpio*), goldfish (*Carassius auratus*), tench (*Tinca tinca*), roach (*Rutilus rutilus*), oriental waterloach (*Misgurnus anguillicaudatus*), eastern gambusia (*Gambusia holbrooki*) and redfin perch (*Perca fluviatilis*) (Lintermans, 2007).

44.2 FISHERIES OVERVIEW

Historically, aboriginal people harvested most moderate-to large-sized fish species in the rivers, lakes and wetlands of the Murray–Darling (Humphries, 2007). It is believed that the most common were golden perch (*Macquaria ambigua*), river catfish (*Tandanus tandanus*), yabby (*Cherax destructor*) (Humphries, 2007) and the Murray cod (*Maccullochella peelii*) which is also a cultural icon of indigenous Australians (Lawrence, 1971). The arrival of European settlers in the eighteenth century led to a change in fishing attitudes, with commercial fishing for Murray cod and other species beginning in 1859 to meet demand for fish in local towns, the goldfields and cities (Rowland, 1989). Commercial fishing was documented as being intensive and fish were taken regardless of size and age, ignoring spawning times and nursey habitats (Humphries, 2007). Up to the 1960s people in inland regions continued to catch and use fresh fish as an important part of their diet (Rowland, 2004).

Early commercial fishing operations exploited species such as Murray cod, golden perch and Macquarie perch (Rowland, 1989). From peak catches in 1918, the commercial fishery on the Murray–Darling gradually declined until the 1960s when there was a dramatic drop and the fishery became unprofitable. The last commercial fishery on the Murray–Darling closed in 2001 (Rowland, 2004). Native fish are still exploited today and provide opportunities for recreational angling, which is hugely popular and contributes to rural economies through tourism (Henry and Lyle, 2003). The main recreational target species are the Murray cod and golden perch (Brown, 2010; Hunt *et al.,* 2010).

Fishing methods

Historically, aboriginal fishers used a variety of methods to catch fish (Lawrence, 1971). Fish were caught using spears both from the bank and from canoes. Brush weirs were also used to trap fish in floodplains, rock chutes funnelled fish to areas where they could be speared easily and hooks were used to catch large fish (Lawrence, 1971; Gerritsen, 2001). Early commercial fishing activities used bag nets or gillnets, sometimes as long as 200 m, which were often strung right across the river. Until 1992 there were few regulations on the Murray–Darling fishery in New South Wales and the use of illegal fishing methods such as cross-lines, drum nets and wire traps was common (Rowland, 2004). Most recreational fishing uses hook and line (including the use of bait, lures and set lines) (Henry and Lyle, 2003).

Fish trade

The recreational fisheries of the Murray–Darling Basin contributes an estimated AUD 1.35 billion annually to the Australian economy (Ernst and Young, 2011). This is through direct purchase of fishing licences, and indirectly through secondary industries such as supplying fishing equipment and bait and accommodation (Ernst and Young, 2011).

Participation in fisheries

Table 44-2 indicates participation rates for the Murray–Darling Basin for 2010 based on census data from 2006; this has been projected forward to 2010 using regional population growth rates. The data represent the number of fishers (aged five or older) that live in the states and territory that the Murray–Darling flows through, therefore the estimate might be low as it does not take into account fishers that travel to the Murray–Darling from outside the states outlined in Table 44-2. However, recreational fishing is an important and popular pastime in Australia, with participation rates as high as 20 percent nationwide, and higher in rural areas such as the Murray-Darling Basin (Henry and Lyle, 2003).

Table 44-2. Participation in Murray–Darling recreational fisheries

State/territory	Recreational fishers
New South Wales	168 661
Victoria	115 448
Queensland	48 395
Southern Australia	36 137
Australian Capital Territory	61 216
Total	**429 857**

Source: Ernst and Young (2011).

Estimated fisheries production

The figures from Table 44-3 indicate the estimated recreational fisheries catch over the period from May 2000 to April 2001. Catch information from Henry and Lyle (2003) was based on the numbers of fish caught rather than weight, due to reliability issues of weight estimations by self-reporting recreational fishers. The weight estimates in Table 44-3 were therefore obtained by multiplying numbers caught by average weight of each harvested individual. Achieving accuracy using this method is difficult as fish populations show structuring based on size over temporal and spatial scales (Henry and Lyle, 2003), therefore the data in Table 44-3 are limited and given the age of the data may not be representative of current fish catches in the basin. The largest portion of the catch was formed by European carp species (1 474 tonnes), which as an invasive species must not be released. Similarly catches of redfin perch, trout and salmon were high (309 tonnes and 200 tonnes) as these fish also cannot be released as they are an invasive species.

Table 44-3. Recreational catch estimates for the Murray–Darling River Basin

State/territory	Catch estimate (tonnes)	Year	Reference
New South Wales	1 526	2001	Henry and Lyle (2003)
Victoria	807		
Queensland	675		
Southern Australia	401		
Australian Capital Territory	24		
Total	**3 433**		

Status of the fisheries: catch trends

Generally, fisheries within the Murray–Darling Basin have declined drastically over the past 100 years, and native fish species are estimated at 10 percent of pre-European settlement populations (Humphries, 2007). Commercial and recreational exploitation are thought to have contributed to declines in large-bodied species such as the Murray cod (MDBC, 2003). Recovery of some fish species is evident, with long-term monitoring indicating that the abundance of Murray cod had increased by 740 percent between 1994 and 2011 (Rowland, 2013). This is partly due to a change in angler attitudes towards catch and release; based on the Henry and Lyle (2003) survey of the 144 tonnes of Murray cod caught by recreational fishers, 77.6 percent was released.

Aquaculture

Large-scale hatchery production of Murray cod, golden perch and silver perch was developed in the 1980s (Rowland, 1989) and commercial hatcheries in New South Wales, Queensland and Victoria started to produce fingerlings (Rowland and Tully, 2004). Broodfish are collected from the wild and held in earthen ponds, and the fertilized eggs collected and placed in separate ponds. Pond management techniques have improved over the past ten years and the survival rate of Murray cod can be as high as 75 percent to 90 percent (Ingram, 2001). In the 2000/2001 season, 1.79 million fingerlings were produced (Ingram and Lawson, 2004), and about 50 percent of all fingerlings produced were sold to commercial grow-out farms (Ingram and Lawson, 2004).

Recreational fishing

Recreational fishing is an important pastime in Australia, with a high participation rate. Recreational fishing contributes significantly towards tourism providing economic benefits to many rural areas (Ernst and Young, 2011). The health of native fish species is reflected in the observed declines in recreational angling success and catch per angler (Koehn and Lintermans, 2012). Traditionally, fishers targeted Murray cod, but effort increased towards golden perch through activities such as species-specific fishing tournaments and changing angler attitudes towards catch and release; golden perch replaced Murray cod as the major native species targeted in recreational fishing (Rowland, 2004; Hall, Broadhurst and Butcher, 2012).

44.3 THREATS TO THE FISHERIES

Invasive species

Native fish species have significantly declined in distribution and abundance while that of invasive species has increased. Native fish populations are 10 percent of their pre-European settlement levels (Murray Darling Basin Ministerial Council 2003). Nine of the native species are threatened, two are critically endangered and 16 are threatened under state jurisdictions (Barrett, 2004). Carp are now the dominant fish of the Murray–Darling Basin and are estimated to represent 60 percent to 90 percent of the total fish biomass with densities as high as one carp per square metre of river surface area (MDBC, 2003; Australian Government, 2004). Changes in water flow, thermal pollution, instream habitat degradation and barriers to fish passage have created conditions that favour invasive species over native fish populations (MDBC, 2005). The mosquitofish is also a serious threat to native fish species. Introduced in the 1920s to prey on mosquitoes, the species has had no impact on mosquito prevalence in the Murray–Darling, but instead attacks and preys upon native fish (Australian Government, 2004). Exotic species have been suggested as a cause for the introduction and dispersal of disease into the basin (Arthington and McKenzie, 1997). Cyprinids, redfin perch and trout have been implicated in the spread of disease in other waterbodies, but specific data on infection of Murray–Darling native fishes is scarce and links between disease and decline in native fish have not been established (Wilson, 2006).

Overfishing

The inland commercial fishery for Murray cod, primarily based on the Murray and Murrumbidgee rivers between the 1880s and 1930s, placed intense fishing pressure on Murray cod populations (Rowland, 2004). The long-lived nature of the Murray cod, with long generation periods, low mortality rates and slow growth, made it very susceptible to overfishing (Reynolds, Dulvy and Roberts, 2002). It is possible that the decline in abundance and CPUE in Murray cod catches was caused primarily by overfishing (Rowland, 2004). Catches of golden perch, silver perch and Murray cod are believed to have declined by 51 percent, 94 percent and 96 percent, respectively in the mid-reaches of the Murray River over a 50-year period (Mallen-Cooper and Brand, 2007). The expanding recreational fishery from the 1970s, combined with illegal fishing that also targeted Murray cod, may also have contributed to the decline of cod. However, river regulation, species introductions and pollution have also contributed as probable causes of declines in the abundance of Murray cod. Therefore, it is likely that a combination of factors is responsible for the declines in native fish species (Wilson, 2006).

River modification

The Murray River is regulated by five tidal barrages, several large dams and 14 low-level weirs; since river development began, an estimated 10 000 barriers to fish migration have been constructed in the Murray–Darling Basin (Baumgartner *et al.,* 2014). Extensive river regulation and fragmentation of the Murray–Darling River have prevented native fish migration and extraction of half the annual flow of the river for irrigation (which accounts for 95 percent of water diversion in the Murray) has increased the periods of low flows that favour invasive species (MDBC 2006). In addition, the periodic release of unnaturally cold water from dams in all but three headwater tributaries prevents warm water native fish from breeding for around 300 km downstream of the barriers (Victorian Government, 2001). For instance, localized extinctions of trout cod, Murray cod and Macquarie perch have occurred 100 km downstream following the completion of the Dartmouth Dam (Barrett, 2004).

Climate change

Projected changes in temperature and rainfall will likely alter the frequency of heavy rains, floods and droughts in the basin. In the northern and southern Murray–Darling Basin reduction of between 8 percent and 12 percent of water runoff is predicted (PMSEIC, 2007). The frequency of droughts is expected to increase by 20 percent to 40 percent by 2030 (PMSEIC, 2007). In some regions, the negative impact of climate change on species such as trout could benefit many native fish species, as water temperatures increase beyond some invasive species thermal capacity (Bond *et al.,* 2011).

44.4 FISHERIES MANAGEMENT

Fish management has traditionally been focused on threatened or angling species, with many other species being neglected (Koehn and Lintermans, 2012). Threatened species management is focused around individual species recovery plans and while they have made gains for some species (e.g. Murray cod) a basin-wide approach is essential (Koehn and Lintermans, 2012).

Native Fish Strategy (NFS) for the Murray–Darling Basin 2003–2013

The NFS is an ecosystem-based approach that uses on-the-ground management to improve the status of native fish species and ecosystem understanding. The NFS represents a commitment among all state jurisdictions to rehabilitate native fish populations by addressing existing threats and reflects the need for coordinated action across state boundaries. The goal of the NFS is to rehabilitate native fish communities of the basin back to 60 percent of their estimated pre-European settlement levels after 50 years of implementation.

Thirteen main objectives of the NFS are directed to improving the status of native fish populations in the basin, the key objectives are:

- Control and manage alien species;
- Provide adequate passage of native fish;
- Protect native fish from the adverse effects of translocation and ensure native fish populations are not threatened by aquaculture;
- Repair and protect key components of aquatic and riparian habitats, including wetlands and floodplains;
- Create and implement management and recovery plans for native fish species; and
- Ensure community and partner ownership and support for native fish management.

Alien fish species are managed through pest management approaches that aim to reduce the populations and prevent the spread of alien species. Immediate implementation of species recovery plans for endangered and native species is essential (MDBC, 2003).

Strict fishing regulations are enforced for the Murray–Darling fisheries, which encourage the release of endangered and native species. Key regulations include:

- Requirement for a recreational fishing licence when fishing in freshwater;
- Size and bag limits for specific fish species, including daily limits, weight limits, line limits compulsory release species and open and closed seasons for some species; and
- Prohibition of release of alien species (NSW Government, 2017).

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45 SEPIK RIVER

45.1 OVERVIEW

The 1 100 km-long Sepik River (Table 45-1) is the longest river system in Papua New Guinea and also drains the largest catchment area (Mitchell, Petr and Viner, 1980). The river also has an average annual discharge of 7 000 m^3/s. The river source is in the Victor Emanuel Range of the Central Highlands of Papua New Guinea near Telefomin. From the source the river flows north–west (crossing the border into Indonesia), and then eastward, the river follows the Central Depression before entering the Bismarck Sea through the large expanse (1 100 km) of delta floodplains. The catchment of the river incudes the Sepik River's largest tributary, the Ramu River, where numerous channels interconnect in the lower reaches where they also share the same floodplain (Dudgeon and Smith, 2006).

Table 45-1. Characteristics of the Sepik River

Country	Area of the river basin (km^2)	Percent area of the river in countries	Population of the river basin	Population density/km^2
Papua New Guinea	76 337	96	1 021 057	13
Indonesia	3 455	4	22 362	6
Total	**79 792**	**100**	**1 043 419**	**10**

Fish diversity

The fish diversity of the Sepik River has been stated as naturally low (Coates, 1993). The total number of species known to occur in the Sepik River Basin is 78 (combined species lists in Allen and Coates, 1990; van Zwieten, 1990; Allen, Parenti, and Coates, 1992; Smith and Flynn, 1998 cited in Dudgeon and Smith, 2006). This is lower than the species richness that would be predicted to occur in an African river of comparable catchment size (Dudgeon and Smith, 2006). The native fish fauna lacks Cyprinidae, but is instead made up of diadromous species and species evolutionarily derived from marine ancestors. The lack of freshwater fish fauna is because Australasian freshwater fish, mainly derived from marine families, generally exhibit ecological characteristics adapted for life in estuaries, not rivers. The Sepik River lacks an estuary, therefore most of the missing 18 Australasian fish families are probably absent for this reason alone (Dudgeon and Smith, 2006). The absence of an estuary has resulted in lack of species diversity in the lowland areas, usually the richest location in this context (Coates, 1993). Also, the river lacks several important riverine habitats. Nevertheless, some native species have adapted to floodplain habitats, for example, the pelagic filter-feeding fork-tailed catfish (*Arius nox*) (Dudgeon and Smith, 2006).

Fish introductions

Owing to the Sepik River being low in fish species, capture fisheries were identified as a means to introduce appropriate species that would fill underutilized or vacant niches (Coates, 1993). Common carp (*Cyprinus carpio*) was introduced in the 1960s and is an important fishery species in the upper reaches. *Anabas testudineus* (the climbing perch) was also introduced into the Sepik River in 1976 after its spread from the Irian Jaya Basin. As part of the Sepik River Stock Enhancement Project (SRSEP 1987–1993) and the Fisheries Improvement by Stocking at High Altitudes for Inland Development (FISHAID: 1993–1997), *Tilapia rendalli, Barbonymus gonionotus, Piaractus brachypomus* and *Prochilodus argenteus* were introduced to the floodplain (Kolkolo, 2003).

45.2 FISHERIES OVERVIEW

The most comprehensive research on the Sepik River fisheries dates back to the 1980s so the following information is outdated but the best available. The Sepik River fishery is essentially a subsistence sector, with most areas and markets being remote and underdeveloped (Coates, 1985). In the past, the only commercial development was a small-scale salted tilapia project (Coates, 1985). Surprisingly, despite the extensive coastline of Papua New Guinea, the freshwater catch was greater than the marine catch and more than 80 percent of the population of the basin depended on fisheries for food (Coates, 1987). Even though the yield was low, the Sepik River supported an important subsistence fishery for inland communities who had no access to marine resources (Coates, 1985). Fishing tended to be seasonal, with most catches and the highest fishing intensity occurring during the dry season when the availability of fish was highest (Coates, 1985). During the 1980s about 50 percent of the fishery catch consisted of introduced *O. mossambicus*; *Cyprinus carpio* was also an important component of fish catches, especially at altitudes where a survey in 1992 indicated that *C. carpio* constituted up to 30 percent of fish catches (Coates and Ulaiwi, 1995). Native species probably contributed 5 percent to 7.5 percent of the fish catches (Coates, 1987). Out of the native species, only the fork-tailed catfish (*Ariidae* spp.) and two species of gudgeon (*Oxyeleotris lineolatus* and *Ophieleotris aporos*) were important in the subsistence fishery (Coates, 1987). The climbing perch was exploited by indigenous communities for its ability to breathe air – they used it as a transportable fresh fish food supply, which helped its diffusion throughout Papua New Guinea (Dudgeon and Smith, 2006).

Fishing methods

Fishery production uses exclusively small-scale fishing gear. Gillnetting was introduced in 1980s and was the main method used by fishers (Coates, 1985). The most significant traditional methods consist of trapping and hook and line from small dugout canoes as well as bow and arrow (FAO, 2010).

Fish trade

The value of the Sepik River fishery is not known but freshwater fisheries production in Papua New Guinea in 2007, which was estimated at 17 500 tonnes, was valued at approximately USD 16.5 million (FAO, 2010). Considering that the fishery on the Sepik River was the largest inland fishery in Papua New Guinea, it is reasonable to assume that most of this value came from the Sepik River.

Employment

The number of people employed in small-scale commercial fishing in Papua New Guinea has never been adequately surveyed and many current estimates are based on a United Nations Development Programme (UNDP) study of the fisheries sector in the late 1980s. Coates (1985) estimated that there were 11 400 fishers in the Sepik River area. This is likely grossly underestimated, given the dependence of inland communities on subsistence fishing and that the Sepik River is the most important fishery in Papua New Guinea. It is therefore not unreasonable to presume that most of the basin population participates in fishing activities at some point during the year.

Estimated fisheries production

Table 45-2 indicates the estimated fisheries production for the Sepik River from Coates (1985). The Sepik River floodplain fishery has a low yield of around 10 percent of that from a similar river at a comparable latitude (Coates, 1985). The figure in Table 45-2 is likely to be an underestimation due to its age and no update since then. It is difficult to estimate the catch for the Sepik River accurately because the area is so remote, has been barely studied and the fishery is predominately for subsistence (Coates, 1985). Detailed studies relating to the fishery only began in 1981 and to date the only reliable catch data for the region is based on gillnet sampling by Coates (1983). Various methods for the estimation of fisheries catches were carried out by Coates (1985). Theoretical estimates based on comparisons with rivers of comparable size in Africa suggest a yield of between 30 000 tonnes/year and 45 000 tonnes/year. Estimated fisheries production based on the number of fishers (assumed to be 11 400), the number of days fished (160 days/fisher based on survey data) and the mean catch/fisher (estimated mean catch of 0.3 tonnes/year) was between 4 364 tonnes/year and 6 395 tonnes/year (Coates, 1985). As the fishery is essentially a subsistence fishery, the amount of fish consumed by people is closely related to the yield. The population of the region (68 000 people on the floodplain in the 1980s) and an assumed consumption of 0.12 kg/day to 0.2 kg/day suggest catches in the region of 3 000 tonnes to 5 000 tonnes/year (Table 45-2).

Table 45-2. Estimated fisheries production for the Sepik River

Catch estimate (tonnes)	Year	Reference
3 000–5 000	n/a	Coates (1985)

Status of the fisheries: catch trends

As the first fisheries surveys were only carried out in 1981 and fish data from then are still the most recent fisheries estimates for which management has been applied, assessing the status of the fishery is not really possible.

Aquaculture

Freshwater aquaculture has been promoted in Papua New Guinea since the 1950s. Until the mid-1990s freshwater aquaculture was the focus of a major national government programme (SRSEP: 1987-1993 and FISHAID: 1993-1997), which included the operation of common carp and rainbow trout hatcheries to restock natural waterbodies with introduced species. Small-scale aquaculture was also promoted (FAO, 2010). To enhance small-scale aquaculture in the region, tilapia fingerlings were distributed to fish farmers in 2002 which helped to overcome the chronic seed shortage. Since 2005, the farming of tilapia has boomed in the country, resulting in a remarkable increase in aquaculture production (FAO, 2010).

Recreational fisheries

Although subsistence fishing has a large social component and is enjoyed by participants, there is little recreational fishing in the Sepik River Basin (FAO, 2010).

45.3 THREATS TO THE FISHERIES

Introduced species

Details of the impact of fish introductions to the Sepik are sketchy (Dudgeon and Smith, 2006). The National Fisheries Authority of Papua New Guinea has undertaken no monitoring in the Sepik River since 1997 due to reorganization of the department and lack of funds. No postintroduction monitoring has been undertaken and the effects of stocking on human welfare have yet to be quantified. In the absence of formal monitoring, observations in the Ramu River suggest impacts on native fauna seem to be severe locally and that some species have not remained confined to the original zones of introduction. Established *C. carpio* and *O. massambicus* have increased the turbidity of the river through benthic grazing. Evidence from fishers suggests that interactions with *C. carpio* have reduced the abundance of gobies in highland tributaries and *O. mossambicus* in lowland areas (van der Heijden, 2002). However, lack of monitoring and available data makes it difficult to distinguish between the effects of introduced species and other anthropogenic influences such as increased fishing pressure from increased population density and adoption of modern fishing gear (Dudgeon and Smith, 2006).

45.4 EQUIVALENT FOOD REPLACEMENT

Fish is an important element of food security in Papua New Guinea. The Sepik River supports the largest fishery in the country and inland freshwater fisheries are considered more important than marine fisheries. The impact of replacement of fisheries on food security would be highly detrimental, especially considering that Papua New Guinea is classed as an LIFCD country. Indeed, FAO (2010) described animal protein substitutes for fish as extremely fatty which would have negative health implications.

Given this information, equivalent food replacement estimates were established for a 50 percent loss in the capture fishery (average of the range from Table 45-2). Replacement food consists of aquaculture (common carp and tilapia), livestock, (beef, pork and chicken) and cassava. Replacement estimates only refer to Papua New Guinea.

Table 45-3. Food production (tonnes), water (million m³), land (km²) and net increase in carbon emissions (thousand tonnes) required to replace kilojoules from inland fisheries and percentage of total current food production, agricultural water use and global pasture-/agricultural land and inland water area

Replacement food	Food production to replace kilojoules from fisheries (percentage of current food production)	Water required to replace fisheries in million m³ (percentage of agricultural water use)	Land required to replace fisheries in km² (percentage of inland water area/pastureland or agricultural land)	Additional greenhouse gas emissions from replacement of fisheries (thousand tonnes)
Common carp	2 417 (537.1)	7.5 (754)	402 (0.5)	
Tilapia	2 366 (145.6)	7.1 (708)	108 (0.1)	0.62
Beef	2 483 (73.5)	38.3 (3 828)	286 (15.1)	155.48
Pork	1 289 (1.8)	7.8 (777)	177 (9.3)	0.71
Chicken	4 090 (65.8)	17.7 (1 769)	110 (5.8)	9.68
Cassava	2 967 (2.0)	5.4 (541)	3 (0.09)	

Energy replacement (Table 45-3)

Aquaculture practices would have to increase substantially to replace capture fisheries. Common carp production would require the equivalent of 537 percent of the farmed common carp production (farmed common carp production was 450 tonnes in 2015). Farmed tilapia production would require the equivalent of 146 percent of the production (production was 1 625 tonnes in 2015). Beef production would require the equivalent of 73.5 percent of production (in 2014 beef production was 3 377 tonnes). Chicken would require the largest increase in production or 65.8 percent of production, which was 6 220 tonnes in 2014.

Water demand (Table 45-3)

Replacement of capture fisheries with beef would have the largest impact on freshwater resources. Beef production would require the equivalent of 3 828 percent of agricultural water use in Papua New Guinea (agricultural water use was 0.01 km³ in 2016). Chicken production would require 17.7 million m³ of water to replace fisheries, equivalent to 1 769 percent of agricultural water use. Aquaculture products (common carp and tilapia) would require similar amounts of water to replace capture fisheries, equivalent to 754 percent and 708 percent of agricultural water use, respectively. Pork production would require the equivalent of 777 percent of agricultural water use. Cassava production would require the smallest increase in water use, equivalent to 541 percent of total agricultural water use.

Land requirements (Table 45-3)

Replacement beef production would require the largest land conversion, equivalent to 15.1 percent of the current pastureland use in Papua New Guinea (pastureland area in 2014 was 1 900 km²). Chicken production would require the smallest land conversion from an animal source, equivalent to 5.8 percent of pastureland. Cassava production would require the equivalent of 0.09 percent of the arable land (2014 arable land area was 3 000 km²).

Greenhouse gas emissions (Table 45-3)

Estimated carbon emissions from 50 percent of fishery production in the Sepik River were 15 040 tonnes. Replacement of capture fisheries would result in a net increase in carbon emissions, which would be highest for beef replacement (155 485 tonnes). Chicken production would have the next highest net increase of 9 688 tonnes, followed by pork production (718 tonnes) and farmed tilapia (615 tonnes).

45.5 FISHERIES MANAGEMENT

Most of the fishing is on a small-scale subsistence basis, where most management interventions are undertaken by local communities. Previous management strategies consisted of the introduction of exotic species to enhance and improve the species diversity of the river to improve fisheries prospects, but this has not been carried out since the 1990s.

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