Food and Agriculture Organization of the United Nations

NFIFL/C1284(En)

FAO
Fisheries and
Aquaculture Circular

ISSN 2070-6065

THE ROLE AND POTENTIAL OF INLAND FISHERIES IN LOW-EMISSION FOOD PRODUCTION AND CLIMATE CHANGE MITIGATION

FAO Fisheries and Aquaculture Circular No. C1284 NFIFL/C1284(En)

THE ROLE AND POTENTIAL OF INLAND FISHERIES IN LOW-EMISSION FOOD PRODUCTION AND CLIMATE CHANGE MITIGATION

David Coates
Consultant

Robert Arthur
Food and Agriculture Organization of the United Nations

Abigail Bennett
Michigan State University

Edith Gondwe
Michigan State University

Roshani Shrestha
Michigan State University

John Valbo-Jørgensen
Food and Agriculture Organization of the United Nations

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2025

Required citation:
Coates, D., Arthur, R., Bennett, A., Gondwe, E., Shrestha, R., Valbo-Jørgensen, J. 2025. *The role and potential of inland fisheries in low-emission food production and climate change mitigation*. FAO Fisheries and Aquaculture Circular No. 1284. Rome, FAO. https://doi.org/10.4060/cd4601en

ISBN 978-92-5-139665-0

Preparation of this document

This document has been produced in a collaboration between FAO and Michigan State University to provide a more nuanced picture of the impacts of fisheries on climate. It builds on FAO's range of publications on fisheries and climate change as part of the efforts of the organization towards sustainable food systems and food and nutrition security.

Abstract

Food from inland capture fisheries is an important service provided by aquatic ecosystems critical to livelihoods and food and nutrition security. But little or no attention has been given to the fact that it has extremely low greenhouse gas (GHG) emissions and thus avoids GHG emissions from other animal source protein that would have to be produced to replace it. Attributional avoided GHG emissions (those from current production) and consequential avoided emissions (from a future change) are calculated based on a comparison with livestock emissions as the reference (replacement from marine fisheries is not viable as limits on production have been reached, and the literature suggests that emissions from the aquaculture sector might be similar to or higher than those from livestock). The bulk of catches from inland food fisheries comes from small-scale non-motorized gears, using either no vessels or predominantly non-motorized vessels, and catches are mainly consumed locally and thus require little energy for transport and processing. Exceptions exist for individual local fisheries, but even these have relatively low emissions. Globally, the production of inland fisheries represents current attributional avoided emissions in the region of 215 million tonnes of carbon dioxide equivalent, about 3.5 percent of total livestock emissions based on the combined (average) emissions from livestock; but these figures include areas with high livestock production but limited inland fisheries. Based on a carbon market price this represents a monetary value of about USD 20 billion annually, or in the region of about half a trillion US dollars in capital value. Estimates for example countries with significant inland fisheries provide more meaningful comparisons, where relative avoided GHG emissions depend on the extent of inland fishery production and total national GHG emissions. These are significant values in all cases, ranging from 3.5 percent to 17.1 percent of national GHG emissions from energy and industry for Viet Nam and Cambodia respectively, among countries in Asia, and between 66.1 percent and 184.4 percent for the United Republic of Tanzania and Malawi, among countries in Africa. These avoided GHG emissions are entirely invisible in current relevant policy forums and related climate change mitigation investment. They are in addition to the other benefits arising from inland fisheries, and there are considerable additional synergies with other ecosystem services provided by the habitats upon which the fisheries depend. The results highlight the need to recognize the values of avoided GHG emissions from inland fisheries in policy, planning and investment, including for climate change mitigation and carbon financing, to ensure their sustainability and achieve sustainable food production systems and progress towards net zero.

Contents

Tables

Figures

Acknowledgements

The authors acknowledge valuable comments on an earlier draft from Anders Faaborg Poulsen and Laure-Sophie Schiettecatte; and they are grateful for the editing and layout provided by Evan Jeffries and Chorouk Benkabbour respectively.

1. Introduction

The Paris Agreement (United Nations, 2015) recognized the urgency of reducing greenhouse gas (GHG) emissions to mitigate climate change. The Intergovernmental Panel on Climate Change (IPCC) has consistently drawn attention to agriculture – and particularly the livestock sector – as a source of anthropogenic emissions (e.g. IPCC, 2022). Livestock account for about 12 percent of all anthropogenic GHG emissions based on the reference year 2015 (FAO, 2023). There is much attention given to reducing emissions from high-emission animal source protein production systems, but much less attention is given to sustaining production from existing low-emission systems. This applies especially to low-emission animal source protein food production that is under threat, where losses would need to be compensated for by increased production from higher-emission systems. This applies to fisheries, and in particular to inland capture food fisheries where emissions are particularly low but threats to production are increasing. This report provides the evidence to support increased awareness and consideration of the value of inland capture food fisheries for avoided GHG emissions.

Comparative GHG impacts of goods (or services) are estimated as the difference between the life-cycle GHG inventory of an assessed product and an alternative reference product that provides an equivalent good (or service). Where the assessed product emits less over its life cycle compared to the reference product the difference is referred to as "avoided emissions", the subject of much attention in climate change mitigation; e.g. renewable energy to replace fossil fuels, or shifting food systems to lower GHG footprints, are both about avoided emissions. According to World Resources Institute guidelines (Russell, 2018) avoided emissions can be represented in goods and services already being produced ("attributional" in GHG accounting) or estimated based on projections of a future action or change in policy or investment ("consequential" in GHG accounting). The two are inter-related for inland food fisheries because although there can be potential to improve production (through improved management and ecosystem restoration), overall they are in decline and highly threatened (FAO, 2024); for example, production from the world's largest inland capture fishery in the Lower Mekong River Basin has already declined by 30 percent in the last two decades, and a further 40 percent reduction is predicted in the near term (MRC, 2023). Hence, changes in policy and investment (consequential avoided emissions) are required to sustain current production (attributional avoided emissions).

The reference for inland capture food fisheries is livestock, using protein equivalent as the common denominator; that is, losses in fisheries, or potential increases, are most likely to be compensated for, or produced by, livestock alternatives. In principle, plant-based proteins provide a logical and sometimes low emission alternative, but realistic comparisons must consider likely trends that are for increased production of animal source protein, including that per capita consumption of animal foods is considered insufficient for many low-income populations (Willett *et al.,* 2019). As elaborated further below, marine fisheries, with higher emissions than inland fisheries but still lower than for livestock, are not a viable reference because they are considered globally fully exploited or overexploited (FAO, 2024). Also elaborated further below, reliable comparative assessments for aquaculture overall are not available, and although some systems have low emissions, others have higher emissions than for livestock, and current information suggests that, overall, the sector may have equivalent emissions to livestock.

There have been attempts to assess GHG emissions from fisheries, but these have usually been focussed on marine fisheries (e.g. Clark and Tilman, 2017; He *et al.*, 2018; Hilborn *et al.*, 2018; Koehn *et al.*, 2022) whereas inland capture fisheries have quite different characteristics

relevant to their emissions. Attention to GHG emissions from inland capture fisheries has been more limited. For example, Ainsworth *et al.* (2018) presented figures for GHG emissions from inland fisheries and estimates of emissions from a selection of potential replacement foods, but without further details of the methodology or sources of data; the comparisons with alternative replacement foods were also based on energy content, whereas protein content is more relevant. The results were used in Ainsworth *et al.* (2021). Harrod *et al.* (2018) recognized that inland fisheries are an extremely climate-friendly system of food production, with a low carbon footprint, but provided no quantification or basis for this conclusion. McGrath *et al.* (2020) drew attention to the potential for fish to drive low-carbon emission food production strategies for the Amazon, based on savings from avoided deforestation, but limited methodological detail was provided.

This report provides a general assessment and methodology for calculating GHG values of inland capture fisheries that compares their emissions to those from replacement livestock production, the most likely source of animal source protein should production need to be compensated; that is, through GHG emissions avoided. The results presented here are general and provide a convincing case for increased recognition of these GHG values, to promote investment in sustaining or increasing production from these fisheries.

2. Methodology and assumptions

In this study, general estimates are made and there are potential sources of variation in the estimates depending on the assumptions and data sources. Collectively these will result in the actual avoided GHG values being higher than those derived here (as explained below); that is, these estimates are conservative. The approach is to compare the estimated GHG emission intensity from inland capture fisheries to the emission intensities from replacement animal source protein for which comprehensive comparative data are available. In the absence of robust projections in trends in consumption patterns, for the comparisons made here it is assumed that current dietary preferences in relevant regions will be maintained. This is a conservative approach, since in developing countries, where the main inland food fisheries occur, as populations become more affluent, they tend to consume more higher-emission foods such as beef.

2.1 INLAND CAPTURE FISHERY PRODUCTION ESTIMATES

The most significant source of known errors in the data used here are the available figures for inland capture fishery production. FAOSTAT compiles national fishery production estimates. FAO (2024) is the latest summary of these data and is the source used here, except as listed otherwise below. Inland capture fishery catch statistics have been consistently recognized to be significantly underestimated and inland fish catches could be 0.3 to 5.0 times higher than official reports (Coates, 2002; World Bank, 2012; Bartley *et al.*, 2015; Fluet-Chouinard, Funge-Smith and McIntyre, 2018; Ainsworth, Cowx and Funge-Smith, 2021). In addition, most production figures refer to finfish only, whereas significant production of other aquatic animals, including amphibians, reptiles, crustaceans, molluscs and insects, and in some cases plants, goes unreported. For the Lower Mekong River Basin, for example, this would add 25 percent to the finfish production figures (MRC, 2023).

Production figures for the Lower Mekong River Basin (in Cambodia, the Lao People's Democratic Republic, Thailand and Viet Nam) used here are based on the comprehensive estimates made by MRC (2023), including other aquatic animals added to finfish production. For Myanmar, Ainsworth *et al.* (2018) cited a production of 1 200 000 tonnes annually for the Irrawaddy River Basin only but noted that FAO considered this an overestimate. Consequently, FAO (2024) put the figure at an average of about 840 000 tonnes for 2019–2022, an implied error of about 30 percent from the previous figure, but nevertheless pointed out that this was now thought to be an underestimate. In this study, a rounded 1 million tonnes was used solely for the Irrawaddy River Basin, although that covers most of Myanmar.

2.2 GHG EMISSION INTENSITY FROM LIVESTOCK

Gerber *et al.* (2013) was used as the source methodology for the baseline emission intensities for reference livestock production systems. Livestock GHG emissions are available from the Global Livestock Environmental Assessment Model (GLEAM)[1] and its associated database the GLEAM dashboard version 3.[2] This database provides GHG emissions data for various individual livestock production systems: beef, buffalo, pig, chicken, goat and sheep; by herd type (beef, dairy, chickens, pigs); by production method (backyard, broiler, feedlots,

[1] https://www.fao.org/gleam/en/
[2] https://foodandagricultureorganization.shinyapps.io/GLEAMV3_Public/

grassland, industrial, intermediate, layer, mixed); and by commodity type (meat, milk, eggs, or as protein). There are significant regional differences in emission intensity due to variations in livestock production efficiencies. Data are searchable for Asia, Africa, Americas, Europe and World. Data for "combined emissions" from all livestock (by region) are available and represent the emissions from all livestock combined for the region in question, subsequently averaged for GHG emission intensity per total kilogram of protein produced. Therefore, the estimates of avoided GHG emissions from inland capture fisheries using the reference "combined" livestock emissions are based on the assumption that production is replaced by a livestock sector with the same composition of sub-sectors and production methods as are currently in place in the region in question. Various reference emission intensities ($kgCO_2$-eq per kg of protein) used for comparison with assessed inland fisheries are shown in Table 1.

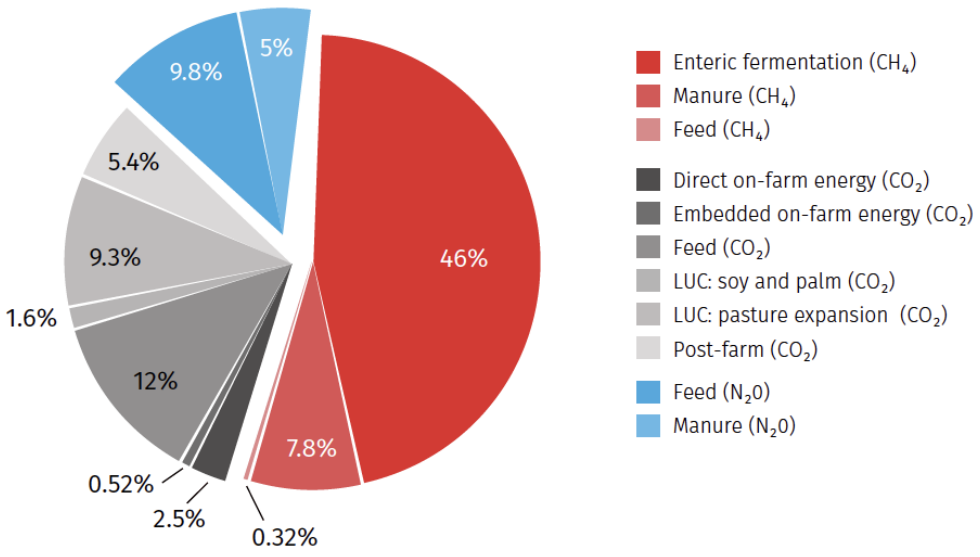
TABLE 1: Greenhouse gas emission intensity from livestock production systems by commodity and region

Region/production system	Emission intensity *($kgCO_2$-eq per kg of protein)*
Asia	
Beef	644.58
Chicken	36.88
Pig	58.78
Combined	69.70
Africa	
Beef	815.99
Chicken	27.71
Pig	56.14
Combined	156.80

Source: **FAO**. 2023. *Pathways towards lower emissions – A global assessment of the greenhouse gas emissions and mitigation options from livestock agrifood systems*. Rome, FAO. https://doi.org/10.4060/ cc9029en

FAO (2023) provides estimates of emissions by source across the livestock production life cycle (Figure 1); these are used as the baseline for comparison of potential sources of emissions throughout the inland capture fisheries life cycle.

FIGURE 1: Total emissions by sources calculated with GLEAM 3



Notes: (percentages are rounded to two significant digits, all in CO_2-eq). CH_4 = methane, N_2O = nitrous oxide, CO_2 = carbon dioxide, LUC = land-use change.
Source: **FAO**. 2023. *Pathways towards lower emissions – A global assessment of the greenhouse gas emissions and mitigation options from livestock agrifood systems*. Rome, FAO. https://doi.org/10.4060/ cc9029en

2.3 GHG EMISSION INTENSITY FROM INLAND CAPTURE FISHERIES

Potential GHG emissions from inland capture fisheries are estimated based on all known potential sources, grouped in the same categories as for livestock (Figure 1). Emissions are zero for enteric fermentation since that applies to ruminants only; land-use change where inland capture fisheries are impacted by land-use change but do not cause it, unless involving ecosystem restoration (see discussion); feed as there is no external feeding of inland capture fishery stocks; and "manure" is absent, but even if there were arguably potential emissions from that source it is natural and therefore irrelevant in terms of anthropogenic GHG emissions.

For inland capture fisheries, the equivalent of "direct and embedded on-farm energy use" (Figure 1) is energy use in fishing operations – essentially the fuel used in catching the fish, including travelling to and from fishing grounds, and the energy used in gear construction. There is insufficient data to attempt an accurate estimate of the energy use in inland fisheries up to the point of harvest (equivalent to direct and embedded on-farm energy use for livestock). However, for livestock, these energy sources account for only 3.02 percent of total emissions (Figure 1). There is a high degree of confidence that equivalent emissions from inland capture fisheries (overall) would be considerably lower. FAO, Duke University and WorldFish (2023) provide the definitive source of information on inland fishing operations compiled as regional or world averages: small-scale fisheries account for 100 percent of the total inland fisheries catch from most regions (except Africa, where it is 99 percent); the vast majority of fish is caught using passive (non-motorized) gears, and where vessels are used they are overwhelmingly non-motorized. Funge-Smith *et al.* (2023) estimate that less than 5 percent of the total inland catch is listed as coming from gears in the category "actively hauled drag nets, trawl nets, large fence traps, large river traps, and bagnets", and even in that category the traps and bagnets are usually passive gears or manually operated in inland capture fisheries. The same source notes that over 85 percent of production comes from non-mechanized sources, with the bulk of the remainder coming from low-energy battery or engine-powered attracting lights, with engine-powered winches and haulers accounting for less than 2 percent. Regarding vessel use, Gutierrez *et al.* (2023) estimate that 75.6 percent of inland fishing operations either use no vessel or a non-motorized vessel; 23.7 percent involve outboard motors of less than 25 hp, and 0.8 percent involve inboard motors of greater than 40 hp. However, the extent of use of these engines in fishing operations is not known; most are considered multi-purpose. Most fishing trips are short-duration or day fishing and are therefore local. Only 4 percent of the total catch comes from multi-day fishing; 49.7 percent of the catch comes from foraging, which is assumed to involve limited, and more likely no, engine use.

These assumptions on energy use are supported by detailed knowledge of specific fisheries. For example, passive gears account for almost all the catch from the Lower Mekong River Basin (MRC, 2023). MRC recorded catches from 14 types of gears over one year at all sites in Cambodia and found that catches from motorized gears were negligible, with over 99 percent of the total catch coming from static, non-motorized gears. SEAFDEC-Sweden (2018) recorded 18 types of fishing gears, none motorized, in the Mekong River in Bokeo Province in the Lao People's Democratic Republic. The Office of National Water Resources (2022) reported the catches from various fishing gears in provinces along the Mekong River in Thailand in 2021: only 85 to 315 fishing boats were operating in each province, with none of them operating mobile (engine-driven) gears and most being multi-purpose. In the inland areas of the Lower Mekong River in Vietnam no motorized gears are used (Nguyen *et al.*, 2006).

No data are available on the embedded GHG emissions from the construction of fishing gears. However, there is confidence that these would likely be much lower than figures for

livestock arising from sources such as fences, animal husbandry equipment, and especially embedded emissions from buildings and machinery.

"Post-farm" emissions from livestock (Figure 1) includes processing (including dealing with wastes), packaging, storage (including refrigeration) and transport to markets. It does not include emissions after the consumer receives the livestock product (mainly from domestic refrigeration and cooking). There is very limited information on comparable sources for inland capture fisheries. However, the widely held view (e.g. Welcomme *et al.*, 2010; Bennett *et al.*, 2018) is that the bulk of the catch is consumed near where it is caught, with a high proportion going directly into fishing households' own consumption. The aforementioned data on the proportion of the catch obtained via various fishing operations (e.g. nearly half comes from foraging, and short-duration fishing trips dominate) gives confidence that overall energy use in transporting the catch would be minimal. There are limited comprehensive data on the processing of the overall inland fish catch, but the same logic supports the view that most of the fish is consumed locally, fresh and (importantly) without significant refrigeration. Salting, drying, smoking and fermentation probably account for most of the processing that occurs. Salting and fermentation are considered negligible in energy use. Drying is usually by solar means, and smoking is usually by fuel wood, with the overall proportion coming from renewable energy sources unknown. Also, most of the inland catch consists of small fish, whereas livestock usually require more butchering and distribution, that entail greater emissions from transportation and preservation. Refrigeration can be significant in some specific local fishery operations, particularly where a high-value product is exported, but this is considered minimal in terms of the proportion of the overall catch. In addition, a large but unquantifiable proportion of the inland fishery catch is consumed (or processed) whole with minimal wastage, which is certainly expected to be less than for livestock. Data are therefore lacking to make a reasonably accurate estimate of overall post-harvest emissions from inland capture fisheries. However, there is confidence that they are lower, and probably much lower, than for livestock. Emissions from this source represent only 5.4 percent of total livestock emissions and it is concluded that post-harvest emissions from inland fisheries are minimal compared to overall emissions from livestock. In addition, emissions from consumers are likely to be lower than for livestock because fish in general require much less energy to cook.

A conversion factor of 0.2 (20 percent) from fresh fish whole catch weight to equivalent weight of protein was used (based on data in Table 2).

TABLE 2: Published data on the percentage protein content of freshwater fish species

Percentage protein *(wet weights)*	**Analyses for**	**Reference**
24.19–32.79	5 freshwater fish species in Bangladesh	Pawar and Sonawane (2013)
16.16–22.28	21 small indigenous fish species in Bangladesh	Hossain *et al.* (1998)
17–22	8 freshwater fish species in Thailand	Puwastein *et al.* (1999)

Sources: **Hossain, M.A., Afsana, K. and Azad Shah, A.K.M.** 1999. Nutritional value of some small indigenous fish species (SIS) of Bangladesh. *Bangladesh Journal of Fisheries Research*, 3: 77–85. **Pawar, S.M. and Sonawane, S.R.** 2013. Fish muscle protein highest source of energy. *International Journal of Biodiversity and Conservation*, 5(7): 433–435. *Sciences*, 365(1554): 2881–2896. **Puwastien, P., Judprasong, K., Kettwan, E., Vasanachitt, K., Nakngamanong, Y. and Bhattacharjee, L.** 1999. Proximate composition of raw and cooked Thai freshwater and marine fish. *Journal of Food Composition and Analysis*, 12(1): 9–16.

The above are generalizations applying to inland capture fisheries as a whole. There are exceptions for individual fisheries and commodities. For example, some products such as caviar or filleted fish for export markets will have much higher post-harvest emissions, but these are outliers and are not representative of the vast majority of inland fisheries. A limited number of individual fisheries are likely to have more of the characteristics of marine fisheries, with a higher use of active gears and motorized vessels. This applies particularly to fisheries in larger lakes, inland seas and reservoirs, where deeper open waters allow the deployment

of such gears. One example is the inland capture fishery in Malawi, which is dominated by fishing in Lake Malawi. Here, an above-average use of motorized vessels, greater distances travelled, and greater distances between areas of production and consumers mean that higher emissions might be expected. However, feedback from local experts (Department of Fisheries, Personal Communication) indicates that some 98.6 percent of the catch from Lake Malawi in 2018 was taken by small-scale fishers (Table 3). Of the vessels in use, about 78 percent were non-motorized. Small-scale fishers using motorized craft have engines ranging from 5 hp up to 30 hp in limited cases. Large-scale boats use twin 45 hp motors, a combined 180 hp for pair trawlers. The largest trawlers have engines from 90 hp up to 400 hp, but there were only 48 such vessels in operation. The majority of fish is consumed fresh, locally, and most of the fish distributed further away from Lake Malawi is dried at source (Bennett *et al.*, 2022) with low preservation emissions (particularly limited use of refrigeration) and lower weights to transport. These figures for both harvest and post-harvest emissions for Lake Malawi suggest the fishery would be well below the average of 11 kg CO_2-eq per kg of protein for marine fisheries (see below), and likely less than 5 kg CO_2-eq per kg of protein.

TABLE 3: Some data for the fishery on Lake Malawi for 2018

Total fishing vessels	**15 219**	**100%**
Dugout canoe (no motor)	10 595	70%
Other boats with engines	1 979	13%
Other boats without engines	1 396	9%
Planked canoe (usually used two in tandem with one engine)	1 369	9%
Fish catches from Lake Malawi	**Catch (tonnes)**	**% of total catch**
Total catch from Lake Malawi fisheries	205 814	100.0%
Commercial catch (48 "large-scale" boats in total, all motorized)	2 818	1.4%
Small-scale catch from boats with engines (chilimila)	92 764	45.0%
Smale-scale catch from non-motorised vessels	110 232	53.6%

Source: from national sources, Department of Fisheries Personal Communication.

Although overall emissions from inland capture fisheries are not zero, there is a high degree of confidence that, overall, they are low enough to be considered negligible when compared to livestock. For purposes of mathematical transparency, estimates of avoided emissions made below assume an indicative GHG emission intensity of between 2–4 kg CO_2-eq per kg of protein based on a best estimate. However, this correction factor is outstripped by the known under-reporting of production, for which no allowances are made. Hence, the figures presented here are considered general and indicative, but conservative. Estimates should be refined for individual fisheries covering the full life-cycle on a case-by-case basis.

2.4 COMPARISON GHG EMISSION INTENSITY FROM MARINE CAPTURE FISHERIES

GHG emissions data for marine fisheries should be avoided as a basis for estimating emissions from inland fisheries, except for individual inland fisheries with similar characteristics and where alternative data are lacking. Marine and inland fisheries have vastly different GHG emission intensity profiles. The bulk of the marine catch is taken by large-scale commercial operations and frequently involves travelling large distances for extended periods, which requires a much greater need for refrigeration. The respective share of the total marine catch taken by large-scale fisheries in Africa, the Americas, Asia, Europe and Oceania is 50 percent, 70 percent , 63 percent, 94 percent and 71 percent; of the small-scale marine catch only 1.4 percent is taken without a vessel, only 2.3 percent of vessels are non-motorized with the majority of engines approaching or exceeding 100 hp, 77.6 percent of vessels in the small-scale category use ice or onboard refrigeration, and all large-scale vessels use refrigeration

(Gutierrez *et al.,* 2023). Consequently, GHG emissions from fuel use alone are very high for the marine sector compared to inland capture fisheries. Parker *et al.* (2018) estimated that global fishing fleet produced 179 million tonnes of CO_2-eq, with an average of 2.2 kg of CO_2-eq emissions per kg of landed fish and invertebrates (whole weight); that is, 11 kg of CO_2-eq emissions per kg of protein (using the same conversion factor as for inland fisheries). Hilborn *et al.* (2018) calculated emissions to be lowest for small pelagic fisheries, with large pelagic and whitefish fisheries emitting higher levels, but these were less than 25 kg CO_2-eq per kg of protein. Compared to reference livestock source foods, products derived from marine fisheries and intended for human consumption have relatively low GHG emissions, but they are still much higher than for inland capture fisheries. There will be examples where small-scale marine and inland fisheries have similar characteristics and low emissions, but published data for marine fisheries are based on global catches with comparatively high energy use.

2.5 GREENHOUSE GAS EMISSIONS FROM AQUACULTURE

There is insufficient, and often contradictory, knowledge to use the aquaculture sector as a whole as the reference for avoided GHG emissions from inland food fisheries, other than to assume it would be similar to livestock. Hilborn *et al.* (2018) note that differences in emissions between specific aquaculture products (and, in some cases, for the same product) can vary by a factor of more than 100, depending on the production method used. Unfed species had the lowest impacts, with water pumping having the highest emissions. They recorded the lowest emissions from mollusc mariculture and salmon aquaculture of less than 25 kg CO_2-eq per kg of protein, but the figure was more than 20 times higher for "catfish" aquaculture. Clark and Tilman (2017) examined 142 fishery and aquaculture systems which indicated that, on average, non-recirculating aquaculture (in ponds, fjords, rivers etc.) and non-trawling marine fisheries emitted similar GHGs per unit of food, and had emissions similar to pork, poultry and dairy. Huysveld *et al.* (2013) evaluated the resource use for *Pangasius* catfish (from cradle to farm gate, starting from production of juveniles in hatcheries to the harvest at farm level), with impacts equivalent to 7.3 tonnes of fossil oil per tonne whole weight (about 36.5 kg CO_2-eq per kg of protein). Bosma *et al.* (2011) evaluated the potential environmental impacts of intensive striped catfish (*Pangasianodon hypothalamus)* farming in the Mekong Delta at about 45 kg CO_2-eq per kg of protein. However, Robb *et al.* (2017) estimated 6.85 kg CO_2-eq per kg of protein for the striped catfish system in Viet Nam, followed by 7.9 kg CO_2-eq per kg of protein for Nile tilapia in Bangladesh, and 9.2 kg CO_2-eq per kg of protein for Indian major carps, when excluding emissions from land-use change. However, the average protein yield per tonne of product from aquaculture is also lower than for capture fisheries, mainly due to differences in products involved (Boyd *et al.,* 2022). Determining comparative values for reference GHG emissions from rice-fish systems is particularly challenging, due to widely varying estimates (Bhattacharyya *et al.*, 2013; Lipper *et al.*, 2017; He *et al.,* 2018). There is also often uncertainty regarding whether all emission pathways are included in calculations (e.g. from ponds). Kosten *et al.* (2020) noted that the intense GHG emissions reported for several aquaculture systems are a source of concern and that actual emissions could be multiple times higher than currently estimated, due to inadequate assessment of emissions pathways. Yuan *et al.* (2019) noted the rapid growth in GHG emissions from the adoption of industrial-scale aquaculture. Zhang *et al.* (2022) concluded that the emissions from the aquaculture sector in China offset about 7 percent of the national terrestrial carbon sink, highlighting the importance of accounting for GHG emissions from aquaculture to improve the accuracy of regional and national carbon budgets. Aquaculture also has a wide range of other impacts, including high water demand, the use of chemicals and antibiotics, soil erosion, land-use change, and effects on biodiversity.

3. Findings for avoided greenhouse gas emissions from inland capture fisheries

Indicative attributional GHG emissions avoided through inland capture fisheries regionally and globally are shown in Table 4. The total estimated avoided emission of about 206–210 million tonnes is equivalent to about 3.5 percent of total world livestock emissions in 2015 (the latest year for which data are shown in GLEAM v3). This is not an insignificant amount, but this comparison is distorted by many regions (e.g. the Americas, Europe) and countries (e.g. the United States of America, Australia) which have high livestock production but relatively insignificant inland food fisheries. Comparisons become more meaningful when made at national level (Table 5). Data in Table 5 show the high variation in estimates depend on the reference replacement livestock production system assumed, being an order of magnitude higher for beef.

TABLE 4: Total indicative attributional avoided GHG emissions from inland capture fisheries

Region	Total production 2022 *(million t)*	Protein equivalent *(million t)*	Attributional avoided GHG emission intensity using combined livestock reference *(kg CO_2-eq /kg protein/yr)*	Approximate total attributional avoided GHG emissions *(million t CO_2-eq/yr)*
Africa	3.324	0.6648	152.8–154.8	101.6–102.9
North America	0.068	0.0136	83.4–85.4	1.14–1.16
South America	0.346	0.0692	83.4–85.4	5.80–5.91
Asia	7.174	1.4348	65.7–67.7	94.27–97.14
Europe	0.392	0.0784	39.3–41.3	3.08–3.24
Oceania	0.017	0.0034	58.7–60.7	0.20–0.21
Total	**11.321**	**2.887**	**–**	**206–210**

Notes: Total fisheries production is based on **FAO**. 2024. *The State of World Fisheries and Aquaculture 2024 – Blue Transformation in action*. Rome, FAO. https://doi.org/10.4060/cd0683en. Attributional avoided GHG emission intensity is based on the reference combined livestock emission intensity for the region (from the Global Livestock Environmental Assessment Model, GLEAM) less an estimate of 2–4 kg CO2-eq /kg protein/yr for the assessed product (inland capture fish).

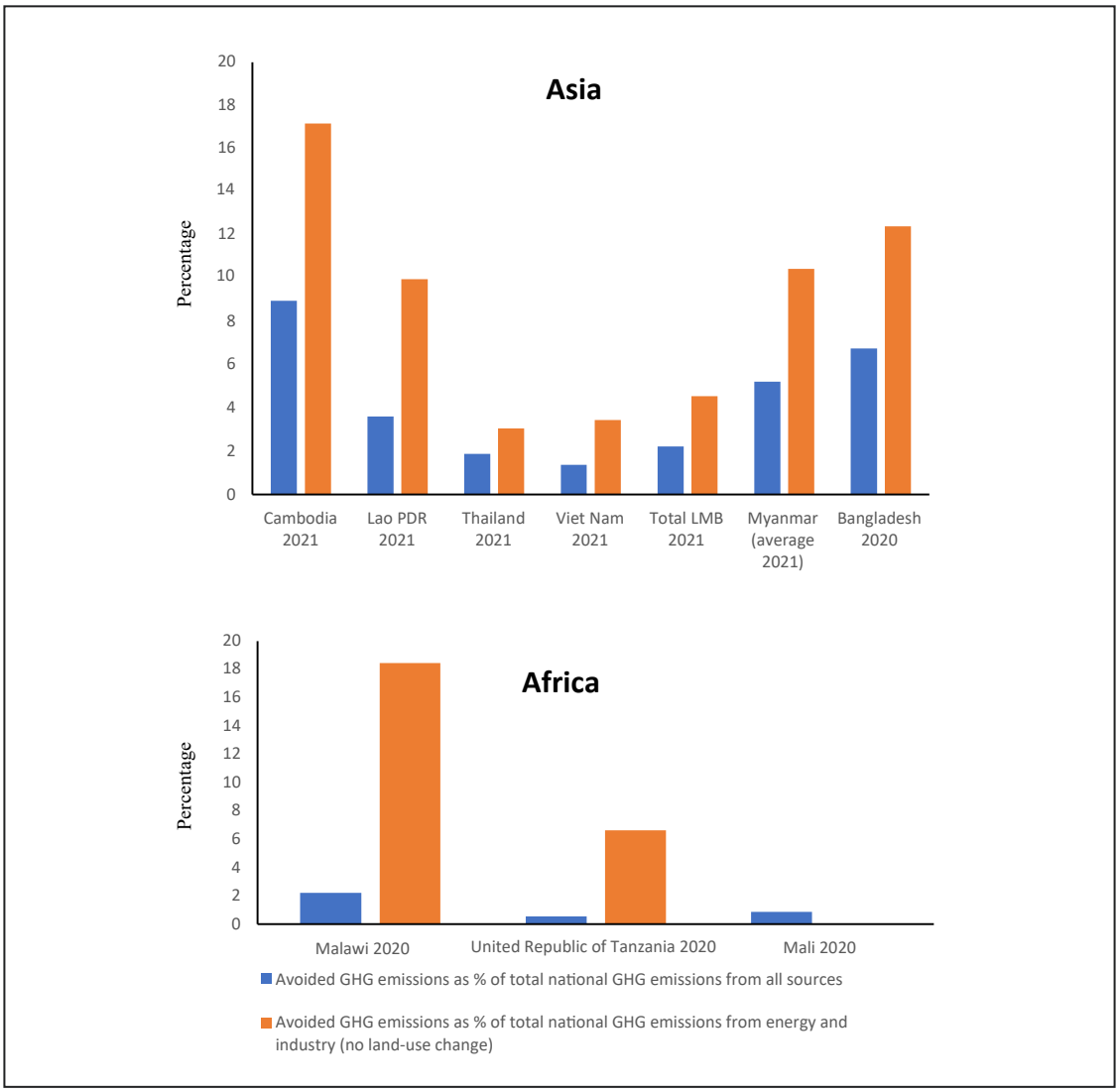
TABLE 5: Total indicative attributional avoided GHG emissions from inland capture fisheries for example countries

Country, year of production	Total inland fisheries production that year *(tonnes)*	Protein equivalent *(tonnes per year)*	Attributional avoided GHG emissions based on reference product as indicated *(million t CO_2-eq per year)*			
			Combined livestock	Beef	Pig	Chicken
Cambodia 2021	516 500	103 300	6.8–7.0	66.2–66.4	5.7–5.9	3.40–3.60
Lao PDR 2021	176 250	35 250	2.3–2.4	22.6–22.7	1.9–2.0	1.22–1.23
Thailand 2021	611 250	122 250	8.0–8.3	78.3–78.6	6.7–6.9	4.10–4.30
Viet Nam 2021	562 500	112 500	7.4–7.6	72.1–72.3	6.2–6.4	3.70–3.90
Total LMB 2021	1 866 500	373 300	24.5–25.3	239.1–39.9	20.4–21.2	12.3–13.0
Myanmar (average 2019–2022)	1 000 000	200 000	13.1–13.5	128.1–128.5	11.0–11.4	6.60–7.00
Bangladesh 2020	1 250 000	250 000	16.4–16.9	160.1–160.6	13.7–14.2	8.20–8.70
Malawi 2020	170 000	34 000	5.2–5.3	27.6–27.7	1.7–1.8	0.81–0.87
United Republic of Tanzania 2020	410 000	82 000	12.5–12.7	66.6–66.7	4.3–4.4	1.90–2.10
Mali 2020	120 000	24 000	3.6–3.7	19.4–19.5	1.2–1.3	0.57–0.62

Notes: Total inland capture fisheries production is based on sources described in the methods and assumptions. Attributional avoided GHG emission intensity is based on the references of beef, pig, chicken or combined livestock emission intensity for the region (from Table 1) less an estimate of 2–4 kg CO2-eq /kg protein/yr for the assessed product (inland capture fish).

The relative scale of the avoided GHG emissions varies between countries according to the level of inland fishery production, the size of the country, and the overall state of development and GHG emissions. Expressing GHG emissions avoided as a proportion of total national GHG emissions (based either on emissions from all sources or from energy and industry alone with no land-use change) helps illuminate relative values (Figure 2). Obviously, where countries have a higher level of industrial and other energy-intensive development, contributions of avoided emissions relative to national GHG emissions are lower (e.g. Thailand, Viet Nam), while they are higher for those with lower national emissions (e.g. Bangladesh, Cambodia, Lao People's Democratic Republic, Myanmar). These are significant values in all cases, ranging from 3.5 percent to 17.1 percent of national GHG emissions from energy and industry for Viet Nam and Cambodia respectively among example countries in Asia, and between 66.1 percent and 184.4 percent for example countries in Africa. Higher values for African countries compared to Asia are due to higher emissions from their livestock sectors (Table 1) and lower total national GHG emissions because of differences in their economies. In all cases these avoided emissions are significant and warrant attention in policy, planning and investment.

FIGURE 2: Indicative avoided GHG emissions of inland capture fisheries as a percentage of total national GHG emissions for the year of production



Notes: Based on a reference of combined livestock production emission intensities for the region, from Table 1. National emissions data are in CO_2-eq from **Ritchie, H., Rosado, P. and Roser, M.** 2023. CO_2 and Greenhouse Gas Emissions. In: *OurWorldInData.org*. https://ourworldindata.org/co2-and-greenhouse-gas-emissions For Cambodia, Lao People's Democratic Republic, Thailand and Viet Nam inland capture fishery production data refer to the Lower Mekong River Basin (LMB) only, whereas emissions data are national.

3.1 MONETARY VALUES OF AVOIDED GREENHOUSE GAS EMISSIONS FROM INLAND CAPTURE FISHERIES BASED ON THE MARKET PRICE OF CARBON

Carbon is traded in markets, which enables data on prices to be used to estimate the equivalent monetary value of avoided GHG emissions from inland capture fisheries. Carbon prices vary between countries and regions and depending on whether they are based on emissions trading schemes, carbon taxes or carbon credits. Some are also heavily influenced by political, rather than economic, factors. The World Bank (2024) maintains a database of systems and prices. For comparative purposes a carbon price of USD 96.20 per tonne of CO_2-eq is used here, based on the European Union Emissions Trading System average price for 2023, due to it being representative across the largest number of countries. Many argue that baseline carbon values should be significantly higher to reflect the true costs of emissions. For example, the latest models of the social cost of carbon calculate a damage of more than USD 3 000 per tonne of CO_2-eq, while values used in policy recommendations range from about USD 50 to USD 200 per tonne CO_2-eq (Kikstra *et al.* 2021).

Equivalent carbon values of inland capture fisheries around the world are indicated in Table 6. Africa and Asia dominate production, accounting for about 92 percent of the total world catch. Although production is about twice as high in Asia, the total carbon value is about the same for Africa because of the much higher reference emission intensities from livestock there. The total world catch is estimated to have a carbon value of about USD 20 billion annually. This is not insignificant. These are annual values. Based on an annual rate of return on capital of 3 percent, USD 20 billion annually equates to a capital value of well in excess of half a trillion US dollars. This clearly indicates an asset worth looking after, particularly when the other values of inland capture fisheries are considered.

There are limited accurate global estimates of the monetary value of this production as food; FAO compiles fisheries product price data for exported commodities only, and this is insignificant for inland fisheries where most is consumed domestically. FAO, Duke University and WorldFish (2023) estimated the economic value of global inland capture fishery production at USD 19 billion based on fish prices at landing. On this basis, the value of the production for avoided GHG emissions is approximately the same as its landed monetary value as food. However, comparisons vary according to the values used along the value chain. For example, the total catch of fish and other aquatic animals for the Lower Mekong River Basin in 2021 was 1.866 million tonnes, with an estimated value of USD 4.075–4.286 billion based on first sale values (MRC 2023), which is about twice the value obtained by using the FAO, Duke University and WorldFish (2023) estimate per unit weight, and over USD 9 billion based on final sales values (MRC, 2023). The carbon value of the catch is about USD 2.5 billion (using the carbon price of USD 96.20 per tonne of CO2-eq specified above). Clearly, carbon values for global avoided GHG emissions add

TABLE 6: Indicative monetary values of avoided GHG emissions of world inland capture fishery production based on the carbon price

Region	Total attributional avoided emissions *(million t CO_2-eq/yr)*	Carbon value *(USD millions per year)*
Africa	101.6–102.9	9 773–9 898
North America	1.14–1.16	110–112
South America	5.80–5.91	558–569
Asia	94.27–97.14	9 069–9 345
Europe	3.08–3.24	296–312
Oceania	0.20–0.21	19–20
Total	**206–210**	**19 817–20 202**

Notes: Total attributional avoided emissions are from Table 4 and the carbon price for 2023 is from the European Emissions Trading System.

Source: **World Bank**. 2024. *State and Trends of Carbon Pricing Dashboard*. https://carbonpricingdashboard. worldbank.org/compliance/price (cited 2 April 2024).

significant value that can rival the value of the catch as food in monetary terms, depending on the comparison values used; although the value of fish as food extends well beyond monetary descriptors.

The carbon value is based on catches being sustained. If the production declines the carbon value becomes a cost incurred through increased GHG emissions from the proportionate increase in livestock production to compensate.

3.2 IMPLICATIONS OF CHANGES TO CURRENT PRODUCTION FROM INLAND CAPTURE FISHERIES

The findings presented here provide a convincing case for investment in sustaining or increasing inland capture fisheries production. If production from inland capture fisheries is reduced, current attributional avoided emissions become real emissions due to the emissions from reference replacement animal source foods; that is, there is a consequential increase in emissions. Likewise, if production from inland capture fisheries is increased, future emissions from increases from alternative reference animal food production that would have occurred are avoided; that is, there is a consequential decrease in emissions.

Inland capture fisheries worldwide are considered highly threatened, mainly from habitat loss and environmental degradation. Worldwide, in 2010, approximately 65 percent of inland waters were assessed as moderately or highly threatened by anthropogenic stressors (Vörosmarty *et al.*, 2010), limiting their ability to support human populations. About 90 percent of the global inland catch originates from systems with above-average stress levels (McIntyre *et al.*, 2016). Citing a real case example, MRC (2017) predicted that the fish populations in the mainstem Lower Mekong River would be reduced by 25–40 percent because of run-of-river hydropower schemes. This does not include the impacts of hydropower schemes constructed on major tributaries, where modelling results indicate that the 78 proposed tributary dams would reduce the biomass of migratory fishes by a further 19 percent (Barlow *et al.*, 2008; Ziv *et al.*, 2012). About 30 percent of the capture fishery production from the Lower Mekong River Basin has been lost since 2000 (MRC, 2023). Such losses are not inevitable, and they are partly driven by policies and investments that do not recognize the value of inland capture fisheries, including from avoided GHG emissions.

Set against this background, it will be challenging to increase overall production from inland capture fisheries. However, there is significant potential in some fisheries and regions. For example, McGrath *et al.* (2020) note the potential for increases from the fishery in the Amazon River Basin, which is currently lightly exploited by world standards, to make a significant contribution to regional low-emission food systems. Worldwide, ecosystem restoration has a track record of driving significant local increases from inland capture fisheries, with potentially significant regional or global impacts if upscaled (Coates, 2023).

4. Implications of the avoided greenhouse gas emissions from inland capture fisheries

These avoided emissions and associated values are more than hypothetical: they have practical implications. Carbon values influence private and public policy and investment both nationally and internationally, and significant sums are involved. For example, the Green Climate Fund is the world's largest climate fund and aims to accelerate climate action in developing countries using flexible financing solutions with a current budget of about USD 13.9 billion,[3] and this is likely to increase significantly. Currently there is much attention, for example, to investing in forest conservation and/or restoration to mitigate climate change by reducing emissions from deforestation and forest degradation in developing countries (REDD+), a strategy recognized under the Paris Agreement. Investing in sustaining or restoring inland capture fisheries involves the same principles, and can also have the considerable advantage of supporting local livelihoods, reducing poverty, and increasing food and nutrition security. Carbon values associated with avoided GHG emissions from inland capture fisheries can also be a significant incentive for investment in the restoration of the habitats upon which the fisheries depend (Coates, 2023). Hence, ecosystem restoration for inland capture food fisheries delivers the combined and interdependent benefits of climate change mitigation through both improved ecosystem carbon sequestration and avoided emissions from food systems, together with poverty reduction and food and nutrition security objectives.

4.1 THE INVISIBILITY OF THE VALUE OF AVOIDED GREENHOUSE GAS EMISSIONS FROM INLAND FISHERIES IN CURRENT POLICIES AND INVESTMENTS

Inland capture fisheries are already recognized as being invisible in relevant policy (e.g. Bennett *et al.,* 2021). The value of inland capture fisheries through avoided GHG emissions is perhaps even more invisible, as illustrated by the following examples.

An assessment of Nationally Determined Contributions (NDCs) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) revealed that 81 percent and 88 percent covered the agriculture and forestry sectors respectively, but only 5 percent referred to mitigation in the fisheries and aquaculture sectors combined – an increase from 2 percent of previous NDCs (Crumpler *et al*., 2021). But these refer principally to reducing energy use in marine fisheries. Of the example countries used above, the most recent NDCs for Bangladesh (UNFCCC, 2021a), Cambodia (UNFCCC, 2020), Malawi (UNFCCC, 2021c), Mali (UNFCCC, 2016), Myanmar (UNFCCC, 2021b) and Viet Nam (UNFCCC, 2022b) reference inland fisheries only with regards to climate change adaptation (the NDC for the United Republic of Tanzania is unavailable). None refer to fisheries in connection with climate change mitigation. Nevertheless, most do refer to other sectors in their mitigation planning, including energy, agriculture, forestry and transport. The NDCs of Lao People's Democratic Republic (UNFCCC, 2021b) and Thailand (UNFCCC, 2022a) make no reference to inland capture fisheries.

A review of GHG emissions from hydropower reservoirs makes no reference to indirect emissions via their impacts on fisheries (Ubierna *et al.,* 2022). The calculation tool for assessing the GHG status of freshwater reservoirs (Prairie *et al.,* 2017) makes no reference to impacts on downstream fisheries. While the extent of these impacts is dependent on the location

3 Based on data at https://www.greenclimate.fund accessed 2 April 2024.

of the dam and the significance of the fishery downstream, attention to the issue is absent even when dams are located where there are known to be high risks for major fisheries. For example, the assessments of the impacts of hydropower dams in the Lower Mekong River Basin generally include impacts on the fisheries sector, but none refer to the implications of this for GHG balances (MRC 2015a, 2015b, 2020b, 2022). A relatively comprehensive study of the protein losses in fisheries caused by dams in the Lower Mekong River Basin (Orr *et al.,* 2012) referenced the increased land and water requirements necessitated by livestock replacement, but did not consider the implications for GHG emissions.

It appears that inland capture fisheries having low GHG emissions may contribute to their invisibility when it comes to climate change mitigation, since attention is usually placed on reducing emissions rather than on avoiding them. This applies even in studies that normally take a more holistic view of ecosystem values. For example, the Economics of Ecosystems and Biodiversity (TEEB) for Agriculture and Food sub-study on inland fisheries (Brugere *et al.,* 2015) recognizes the relatively low GHG emissions of fisheries and considers the impacts of lost fishery production on requirements for replacement food from other sources, but not the implications of losses for increased emissions. Consequently, avoided GHG emission values for fisheries were not included in estimates of ecosystem service values, and those for carbon fixation and GHG emissions only referred to protected areas.

4.2 ADDITIONAL CONSIDERATIONS RELEVANT TO THESE VALUES

The avoided GHG emissions identified here are additional to other important values of inland capture fisheries derived from their role in food and nutrition security, sustainable livelihoods, and poverty reduction (e.g. Bennett *et al.,* 2018; Funge-Smith and Bennett, 2019). The main purpose of highlighting them is to add weight to existing arguments for improved investment in management to sustain or improve these fisheries. In addition, these findings draw attention to the need to integrate inland capture fisheries more closely into broader strategies towards more sustainable food systems, including for reduced GHG emissions. This includes investing in sustaining or restoring the ecosystems upon which they depend (e.g. Coates, 2023), and diversifying potential investment sources, such as through climate change mitigation funding.

The calculation of avoided emissions using protein equivalent is also simplistic and misses the other important nutritional values of fish associated with the high-quality protein involved and their micro-nutrient content (e.g. Bennett *et al.,* 2021). Hilborn *et al.* (2018) used a nutrient richness index for comparing the environmental footprints of different foods to reveal a considerable difference across food production groups. Fish, particularly smaller species, generally had a lower footprint than livestock, with prawns and cultured species (catfish and tilapia) having higher footprints than wild-caught fish. Hence, inland capture fisheries would likely have even higher avoided GHG emissions when factoring in other food values of reference products.

GHG emissions are also not the only source of environmental footprint relevant to comparisons between inland fisheries and alternative animal source foods. Both livestock and aquaculture are major sources of pollution (UNEP, 2023) and antibiotic use (Hilborn *et al.,* 2018). Aquaculture and to a greater extent livestock involve land-use change and water demand. For example, coastal aquaculture has been a major driver of coastal forest and wetland loss (Convention on Wetlands, 2021), and livestock has been a major driver of deforestation (IPBES, 2019). The loss of fish through the construction of dams in the Lower Mekong River Basin is estimated to require an additional 6–17 percent of water and 19–63 percent of land to raise livestock to replace the protein previously supplied by the

fishery (Orr *et al.*, 2012), without considering the reduction in health benefits that are brought by the consumption of fish. There are also consequential increased GHG emissions from associated land-use change. In contrast, inland capture fisheries are relatively non-polluting, have no antibiotic use, involve no direct water use, and do not cause land-use change (except for potential positive change through associated ecosystem restoration efforts).

There can also be significant social differences between foods from inland capture fisheries and livestock. Much of the production from inland fisheries is for subsistence and direct family use. Loss of that resource requires that impacted communities have access to and money to pay for livestock-based substitutes. Many will not have access to resources such as land and know-how to raise livestock themselves. Hence, loss of capture fishery production can create significant inequalities even where overall food availability remains unchanged.

There are also clear synergies between avoided emissions from food provided by inland capture fisheries and the other ecosystem services provided by the principal habitats upon which the fisheries depend, chiefly wetlands, the most valuable ecosystem type per unit area (Russi *et al.* 2013). This includes ecosystem services related to climate change mitigation and adaptation, among others. Such synergies, and potentially trade-offs, are worthy of much greater attention in integrated natural resources management planning.

5. Conclusions

This initial assessment clearly illustrates the significant level and value of avoided GHG emissions from inland capture fisheries, both in terms of sustaining current production as well as the potential benefits from increased production. This adds to the already compelling case to sustain or improve these fisheries for many other reasons. There is a clear and immediate case for recognizing this in relevant policies, planning and investment.

Realizing these values by integrating them into policy, planning and investment will not be easy. Although logical, the approach is novel to many. There are well-entrenched perceptions regarding climate change mitigation to overcome. One is an emphasis on reducing the higher emissions from many current food production systems that can overshadow the value of sustaining and/or expanding existing low-emission production methods. Inland fisheries remain invisible in many policy forums (Bennett *et al.*, 2018; Funge-Smith and Bennett, 2019; Bennett *et al.*, 2021) and are even more so when it comes to their potential role in climate change mitigation. This report aims to raise awareness and shift the dialogue in a more logical and equitable direction.

References

Ainsworth, R. A., Funge-Smith, S. J. & Cowx, I. G. 2018. Chapter 10.3: Assessing Inland fisheries at basin level. In: S.J. Funge-Smith (ed.), *Review of the state of world fishery resources: Inland fisheries*. FAO Fisheries and Aquaculture Circular No. C942 Rev. 3. Rome, FAO.

Ainsworth, R., Cowx, I.G. and Funge-Smith, S.J. 2021. *A review of major river basins and large lakes relevant to inland fisheries.* FAO Fisheries and Aquaculture Circular No. 1170. Rome, FAO. https://doi.org/10.4060/cb2827en.

Barlow, C., Baran, E., Halls, A.S. and Kshatriya, M. 2008. How much of the Mekong fish catch is at risk from mainstream dam development? *Catch and Culture*, 14(3): 16–21.

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

Bennett, A., Basurto, X., Virdin, J., Lin, X., Betances, S.J., Smith, M.D., Allison, E.H., Best, B.A., Brownell, K.D., Campbell, L.M., Golden, C.D., Havice, E., Hicks, C.C., Jacques, P.J., Kleisner, K., Lindquist, N., Lobo, R., Murray, G.D., Nowlin, M., … Zoubek, S. 2021. Recognize fish as food in policy discourse and development funding. *Ambio*, 50(5), 981–989. https://doi.org/10.1007/s13280-020-01451-4.

Bennett, A., Patil, P., Kleisner, K., Rader, D., Virdin, J. and Basurto, X. 2018. *Contribution of fisheries to food and nutrition security: current knowledge, policy, and research.* Nicholas Institute Report 18-02. Durham, USA, Duke University. http://nicholasinstitute.duke.edu/publications.

Bennett, A., Rice, E., Muhonda, P., Kaunda, E., Katengeza, S., Liverpool-Tasie, L.S.O., Belton, B., Infante, D.M., Ross, J., Virdin, J. and Gondwe, E. 2022. Spatial analysis of aquatic food access can inform nutrition-sensitive policy. *Nature Food*, 3(12): 1010–1013.

Bhattacharyya, P., Sinhababu, D.P., Roy, K.S., Dash, P.K., Sahu, P.K., Dandapat, R., Neogi, S. and Mohantym, S. 2013. Effect of fish species on methane and nitrous oxide emission in relation to soil C, N pools and enzymatic activities in rainfed shallow lowland rice-fish farming system. *Agriculture, Ecosystems and Environment*, 176: 53–62, https://doi.org/10.1016/j.agee.2013.05.015

Bosma, R., Anh, P.T. and Potting, J. 2011. Life cycle assessment of intensive striped catfish farming in the Mekong Delta for screening hotspots as input to environmental policy and research agenda. *International Journal of Life Cycle Assessment*, 16: 903–915.

Boyd, C.E., McNevin, A.A. and Davis, R.P. 2022. The contribution of fisheries and aquaculture to the global protein supply. *Food security*, 14(3), 805–827.

Brugere, C., Lymer, D. and Bartley, D.M. 2015. *Ecosystem services in freshwater fish production systems and aquatic ecosystems: Recognizing, demonstrating and capturing their value in food production and water management decisions.* TEEB Agriculture and Food, UNEP, Geneva.

Clark, M. and Tilman, D. 2017. Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. *Environmental Research Letters*, 12(6): 064016.

Coates, D. 2002. *Inland capture fishery statistics for South-east Asia: current status and information needs.* FAO, Regional Office for Asia-Pacific, Bangkok, Thailand. RAP Publication 2002/11.

Coates, D. 2023. *Ecosystem restoration and inland food fisheries in developing countries – opportunities for the United Nations Decade on Ecosystem Restoration (2021–2030).* FAO Fisheries and Aquaculture Circular No. 1231. Rome, FAO. https://doi.org/10.4060/cc7082en

Convention on Wetlands. 2021. *Global Wetland Outlook: Special Edition 2021*. Gland, Switzerland, Secretariat of the Convention on Wetlands. www.global-wetland-outlook.ramsar.org/report-1

Crumpler, K., Abi Khalil, R., Tanganelli, E., Rai, N., Roffredi, L., Meybeck, A., Umulisa, V., Wolf, J. and Bernoux, M. 2021. *(Interim) Global update report – Agriculture, Forestry and Fisheries in the Nationally Determined Contributions.* Environment and Natural Resources Management Working Paper No. 91. Rome, FAO. https://doi.org/10.4060/cb7442en

FAO. 2023. *Pathways towards lower emissions – A global assessment of the greenhouse gas emissions and mitigation options from livestock agrifood systems.* Rome, FAO. https://doi.org/10.4060/cc9029en

FAO. 2024. *The State of World Fisheries and Aquaculture 2024 – Blue Transformation in Action*. Rome, FAO. https://doi.org/10.4060/cd0683en

FAO, Duke University and WorldFish. 2023. *Illuminating Hidden Harvests – The contributions of small-scale fisheries to sustainable development.* Rome. https://doi.org/10.4060/cc4576en

Fluet-Chouinard, E., Funge-Smith, S. and McIntyre, P.B. 2018. Global hidden harvest of freshwater fish revealed by household surveys. *Proceedings of the National Academy of Sciences of the United States of America*, 115(29): 7623–7628.

Funge-Smith, S., and Bennett, A. 2019. A fresh look at inland fisheries and their role in food security and livelihoods. *Fish and Fisheries*, 20(6): 1176–1195. https://doi.org/10.1111/faf.12403

Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. and Tempio, G. 2013. *Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities.* FAO, Rome. https://www.fao.org/4/i3437e/i3437e.pdf

Gutierrez, N.L., Funge-Smith, S., Gorelli G., Mancha-Cisneros, M.M., Defeo, O., Johnson, A.F. and Melnychuk, M.C. 2023. Production and environmental interactions of small-scale fisheries. In: FAO, Duke University and WorldFish. 2023. *Illuminating Hidden Harvests: the contributions of small-scale fisheries to sustainable development*. Rome, FAO; Durham, USA, Duke University; Penang, Malaysia, WorldFish.

Harrod, C., Simmance F., Funge-Smith, S. and Valbo-Jørgensen, J. 2018. Options and opportunities for supporting inland fisheries to cope with climate change adaptation in other sectors. Pp. 567–584. *In*: Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. and Poulain, F., eds. *Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options*. FAO Fisheries and Aquaculture Technical Paper No. 627. Rome, FAO.

He, P., Davy, D., Sciortino, J., Beveridge, M.C.M., Arnason, R., and Gudmundsson, A. 2018. Countering climate change: measures and tools to reduce energy use and greenhouse gas emission in fisheries and aquaculture. Pp. 585–608 In: Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. and Poulain, F., eds. *Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options*. FAO Fisheries and Aquaculture Technical Paper No. 627. Rome, FAO.

Hilborn, R., Banobi, J., Hall, S.J., Pucylowski, T. and Walsworth, T.E. 2018. The environmental cost of animal source foods. *Frontiers in Ecology and the Environment*, 16(6): 329–335.

Hossain, M.A., Afsana, K. and Azad Shah, A.K.M. 1999. Nutritional value of some small indigenous fish species (SIS) of Bangladesh. *Bangladesh Journal of Fisheries Research*, 3: 77–85.

Huysveld, S., Schaubroeck, T., De Meester, S., Sorgeloos, P., Van Langenhove, H. and Dewulf, J. 2013. Resource use analysis of Pangasius aquaculture in the Mekong Delta in Vietnam using exergetic life cycle assessment. *Journal of Cleaner Production*, 51: 225–233.

IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). 2019. *Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.* Bonn, Germany, IPBES. https://doi.org/10.5281/zenodo.3553579

IPCC (Intergovernmental Panel on Climate Change). 2022. *Climate Change 2022 – Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* First edition. Cambridge University Press. https://doi.org/10.1017/9781009157926

Kikstra, J.S, Waidelich, P., Rising, J., Yumashev, D., Hope, C. and Brierley, C.M. 2021. The social cost of carbon dioxide under climate-economy feedbacks and temperature variability. *Environmental Research Letters,* 16 (9): 094037. https://doi.org/10.1088/1748-9326/ac1d0b. S2CID 237427400

Koehn, J.Z., Allison, E.H., Golden, C.D. and Hilborn, R. 2022. The role of seafood in sustainable diets. *Environmental Research Letters*, 17(3): 035003.

Kosten, S., Almeida, R.M., Barbosa, I., Mendonça, R., Muzitano, I.S., Oliveira-Junior, E.S., Vroom, R.J.E., Wang, H.J. and Barros, N. 2020. Better assessments of greenhouse gas emissions from global fish ponds needed to adequately evaluate aquaculture footprint. *Science of the Total Environment*, 748: 141247. https://doi.org/10.1016/j.scitotenv.2020.141247

Lipper, L., McCarthy, N., Zilberman, D., Asfaw, S. and Branca, G. 2017. *Climate smart agriculture: building resilience to climate change*. Springer Nature.

McGrath, D.G., Castelloiii, L., Braboiv, M., Nepstadi, D., da Gama, V.S., Forsberg, B., Mendozai, E., Estupinan Vii, G., Ribeiroi, A., Almeidaviii, O.T., Bentesix, A.J. and Chani, C. 2020. *Policy Brief: Can Fish Drive Development of the Amazon Bioeconomy?* Earth Observation Institute.

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

MRC (Mekong River Commission). 2015a. *The ISH 0306 Study. Development of Guidelines for Hydropower Environmental Impact Mitigation and Risk Management in the Lower Mekong Mainstream and Tributaries. Volume 1 – Hydropower Risks and Impact Mitigation Guidelines and Recommendations – Version 1.0.* Mekong River Commission, Vientiane, Lao PDR.

MRC. 2015b. *The ISH 0306 Study. Development of Guidelines for Hydropower Environmental Impact Mitigation and Risk Management in the Lower Mekong Mainstream and Tributaries. Volume 2 – Version 1.0 – Hydropower Risks and Impact Mitigation MANUAL – Key Hydropower Risks, Impacts and Vulnerabilities and General Mitigation Options for Lower Mekong.* Mekong River Commission, Vientiane, Lao PDR.

MRC. 2017. *Summary of the basin-wide assessments of climate change impacts on water and water-related resources in the Lower Mekong Basin.* https://www.mrcmekong.org/assets/Uploads/Summary-of-basin-wide-impact-assessments.pdf

MRC. 2020a. *Fisheries assessment and diversity monitoring programme.* Mekong River Commission, Vientiane, Lao PDR.

MRC. 2020b. *The MRC Hydropower Mitigation Guidelines. Guidelines for hydropower environmental impact mitigation and risk management in the Lower Mekong mainstream and tributaries (vol. 3).* Mekong River Commission, Vientiane, Lao PDR.

MRC. 2022. *Sustainable Hydropower Development Strategy: A basin-wide strategy for a changing Mekong River Basin.* Mekong River Commission, Vientiane, Lao PDR.

MRC. 2023. *Fisheries Yield Assessment by Habitat Type at The Landscape Scale In The Lower Mekong River Basin 2020.* Mekong River Commission, Vientiane, Lao PDR.

Nguyen, N. Du, Smallwood, C., Nguyen, V.H., Nguyen, X.T. and Nguyen, T.T. 2006. *Collection Atlas on the inland fishing gears in the Mekong Delta.* Publications of Research Institute for Aquaculture 2 and MRC, Ho Chi Minh.

Office of the National Water Resources (ONWR). 2022. *Final Report: A study of the impact and monitoring of transboundary environmental impact assessment of hydropower projects on the Mekong mainstream 2021.*

Orr, S., Pittock, J., Chapagain, A. and Dumaresq, D. 2012. Dams on the Mekong River: Lost fish protein and the implications for land and water resources. *Global Environmental Change*, 22(4): 925–932.

Parker, R.W., Blanchard, J.L., Gardner, C., Green, B.S., Hartmann, K., Tyedmers, P.H. and Watson, R.A. 2018. Fuel use and greenhouse gas emissions of world fisheries. *Nature Climate Change*, 8(4): 333–337.

Pawar, S.M. and Sonawane, S.R. 2013. Fish muscle protein highest source of energy. *International Journal of Biodiversity and Conservation*, 5(7): 433–435. *Sciences*, 365(1554): 2881–2896.

Prairie, Y.T., Alm, J., Harby, A., Mercier-Blais, S. and Nahas, R. 2017. *The GHG Reservoir Tool (G-res) Technical documentation. Updated version 3.2 (2022-12-19). UNESCO/IHA research project on the GHG status of freshwater reservoirs.* Joint publication of the UNESCO Chair in Global Environmental Change and the International Hydropower Association.

Puwastien, P., Judprasong, K., Kettwan, E., Vasanachitt, K., Nakngamanong, Y. and Bhattacharjee, L. 1999. Proximate composition of raw and cooked Thai freshwater and marine fish. *Journal of Food Composition and Analysis*, 12(1): 9–16.

Ritchie, H., Rosado, P. and Roser, M. 2023. CO_2 and Greenhouse Gas Emissions. In: *OurWorldInData.org.* https://ourworldindata.org/co2-and-greenhouse-gas-emissions

Robb, D.H.F., MacLeod, M., Hasan, M.R. and Soto, D. 2017. *Greenhouse gas emissions from aquaculture: a life cycle assessment of three Asian systems.* FAO Fisheries and Aquaculture Technical Paper No. 609. Rome, FAO.

Russell, S. 2018. Estimating and Reporting the Comparative Emissions Impacts of Products. Working Paper. Washington, DC: World Resources Institute.

Russi, D., ten Brink, P., Farmer, A., Badura, T., Coates, D., Förster, J., Kumar, R. and Davidson, N. 2013. The economics of ecosystems and biodiversity for water and wetlands. London/ Brussels/Gland, Institute for European Environmental Policy (IEEP)/Ramsar Secretariat.

SEAFDEC-Sweden. 2018. The SEAFDEC-Sweden Program: Mekong River Sub-region. South-East Asian Fisheries Development Cooperation Program.

Ubierna, M., Santos, C.D. and Mercier-Blais, S. 2022. Water Security and Climate Change: Hydropower Reservoir Greenhouse Gas Emissions. In: Biswas, A.K. and Tortajada, C. (eds), *Water Security Under Climate Change*. Water Resources Development and Management. Springer, Singapore. https://doi.org/10.1007/978-981-16-5493-0_5

UNEP (United Nations Environment Programme)**.** 2023. *The Global Environment Outlook.* United Nations Environment Programme. https://www.unep.org/geo/

UNFCCC (United Nations Framework Convention on Climate Change)**.** 2016. Mali Contribution Déterminée niveau national. United Nations Framework Convention on Climate Change.

UNFCCC. 2020. Cambodia's Updated Nationally Determined Contribution (NDC). United Nations Framework Convention on Climate Change.

UNFCCC. 2021a. Bangladesh updated nationally determined contribution. United Nations Framework Convention on Climate Change.

UNFCCC. 2021b. Lao PDR Updated Nationally Determined Contribution (NDC). United Nations Framework Convention on Climate Change.

UNFCCC. 2021c. Malawi updated nationally determined contributions. United Nations Framework Convention on Climate Change.

UNFCCC. 2021d. Myanmar first nationally determined contribution (updated). United Nations Framework Convention on Climate Change.

UNFCCC. 2022a. Thailand's Second Updated Nationally Determined Contribution (NDC). United Nations Framework Convention on Climate Change.

UNFCCC. 2022b. Viet Nam's Nationally Determined Contribution (NDC) Updated. United Nations Framework Convention on Climate Change.

United Nations. 2015. Paris Agreement. In: *Report of the Conference of the Parties to the UNFCCC (21st Session, 2015)*. Paris.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Reidy Liermann, C. and Davies, P.M. 2010. Global threats to human water security and river biodiversity. *Nature*, 467(7315): 555–561. https://doi.org/10.1038/nature09440

Welcomme, R.L., Cowx, I.G., Coates, D., Béné, C., Funge-Smith, S., Halls, A. and Lorenzen, K. 2010. Inland capture fisheries. *Philosophical Transactions of the Royal Society B,* 1554, 2881–2896. https://doi.org/10.1098/rstb.2010.0168

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S. ... and Murray, C. J. 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet,* 393(10170), 447–492.

World Bank. 2024. State and Trends of Carbon Pricing Dashboard. https://carbonpricingdashboard.worldbank.org/compliance/price (cited 2 April 2024).

Zhang, Y., Tang, K.W., Yang, P., Yang, H., Tong, C., Song, C., Tan, L., Zhao, G., Zhou, X. and Sun, D. 2022. Assessing carbon greenhouse gas emissions from aquaculture in China based on aquaculture system types, species, environmental conditions and management practices. *Agriculture, Ecosystems and Environment*, 338: 108110, https://doi.org/10.1016/j.agee.2022.108110

Ziv, G., Baran, E., Nam, S., Rodríguez-Iturbe, I. and Levin, S.A. 2012. Trading-off fish biodiversity, food security, and hydropower in the Mekong River Basin. *Proceedings of the National Academy of Sciences*, 109: 5609–5614. https://doi.org/10.1073/pnas.1201423109

ISBN 978-92-5-139665-0 ISSN 2070-6065

9 789251 396650

CD4601EN/1/03.25