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Report of the

SECOND ADVISORY ROUNDTABLE ON THE ASSESSMENT OF INLAND FISHERIES

Rome, 25–27 November 2019

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PREPARATION OF THIS DOCUMENT

This document was prepared by the FAO Secretariat with inputs and agreement from the participants of the Second Advisory Roundtable on the Assessment of Inland Fisheries. The financial and technical support the United States Geological Survey for support to participation is gratefully acknowledged.

ABSTRACT

The Second Advisory Roundtable on the Assessment of Inland Fisheries was convened in partnership with United States Geological Service (USGS), from 25 to 27 November 2019. It reviewed progress of work that had been initiated as a response to the recommendations of the "Advisory Roundtable on the Assessment of Inland Fisheries" that was convened in partnership with United States Geological Service (USGS) and Michigan State University (MSU) in FAO Rome, from 8 to 10 May 2018. The Second Roundtable covered two aspects of the assessment of inland fisheries.

As its first task, the Roundtable reviewed a threat mapping framework developed by USGS and University of Florida, which seeks to provide a robust assessment method for inland fisheries and the associated ecosystems/basins upon which they depend. This is intended to support the management of aquatic systems and the continued delivery of ecosystem services. The status map that the analysis provides is a visual (and quantifiable) relative indication of the levels of anthropogenic and natural environmental pressures to inland fisheries at the basin or sub-basin level. Five major threats to inland fisheries (and their 21 sub-threat categories) were scored according to global studies and modelling. Connectivity and land use were the highest weighted variables, with close agreement between literature and expert opinion. Literature and expert opinion disagreed on the relative importance of water abstraction and pollution. The Roundtable noted that the assessment appeared to work better with flowing water/river basins rather than large water bodies. It was also noted that specific and more localized pressures from cities or irrigation and other land uses within basins may have local effects rather than basin-scale impacts. The Roundtable concluded that local expert knowledge will still be required to validate model findings and ground-truth results in the local context. The Roundtable also concluded that the value of mapping pressures is that it enables an objective, downscaled evaluation of potential threats to inland fishery food production and biodiversity at the basin and sub-basin level. It also enables the prioritization of needs for ecosystem restoration and improved conservation.

The second task of the Roundtable was to review the potential of using length-based (LB) assessment methods as a tool to support management advice in data-poor inland fisheries. Simple indicators such as abundance and size distribution of the fish caught in combination with local knowledge enable better understanding of underlying causes of historical trends in a fishery and an indication of the current status of a fish stock. This can be further used to inform planning using the Ecosystem Approach to Fisheries management (EAFm). Where information about the life cycles of the fish (i.e. size at maturity) is available, the Length-Based Spawning Potential (LB-SPR) model can be applied, otherwise, simpler empirical LB models must be used. The two approaches have been applied to data from five inland fisheries: the Tonlé Sap dai fishery in Cambodia; the tilapia fishery in Lago Bayano, Panama; the sábalo fishery in Paraná, Argentina; the goliath catfish fishery in the Amazon Basin and four recreational fisheries in South Africa. The case studies showed that the LB-SPR model can provide consistent inter-annual evaluations of stock state that concur well with local scientific expert judgement, and the model can therefore be used in certain inland fisheries. However, LB assessment methods require a number of assumptions to be fulfilled, and may, in some situations, provide misleading information. They may also be no easier than a standard assessment approach that incorporates fishing effort. The Roundtable suggested some criteria where the LB-SPR approach can be used effectively and agreed that these should be more comprehensively elaborated. With the most data-poor fisheries, the intuitive combination of empirical indicators and expert narrative will be the only effective/practical approach.

CONTENTS

ABBREVIATIONS AND ACRONYMS

USGS	United States Geological Service
MSU	Michigan State University
COFI	FAO Committee on Fisheries
EAFm	Ecosystem Approach to Fisheries management
LB-SPR	Length-Based Spawning Potential Ratio
GIS	Geographic information system
GPD	Gross Domestic Product
SDGs	Sustainable Development Goals
SSB	Spawning stock biomass. Total weight of all sexually mature fish in the stock
CPUE	Catch per unit effort
SPR	Mortality and Spawning Potential Ratio
LB-SPR	Length-based Spawning Potential Ratio
ENSO	El Niño-Southern Oscillation
RP	Reference Points
M	Natural mortality
K	Parameter of the VBGF, of dimension time^{-1}, and expressing the rate at which the asymptotic length (or weight) is approached
L_∞	Asymptotic length
L	Symbol for the individual body length of a fish
Lmax	Maximum individual length on record for a species or one of its populations (depending on context)
M/K	Ratio of natural mortality to growth rate
LEK	Local Expert Knowledge
ParFish	Participatory Fisheries Stock Assessment
SOFIA	The State of World Fisheries and Aquaculture

1. OPENING AND INTRODUCTION

1. The first "Advisory Roundtable on the Assessment of Inland Fisheries", convened from 8 to10 May 2018, in partnership with United States Geological Service (USGS) and Michigan State University (MSU) in FAO, Rome, provided guidance on possible ways to proceed with developing advice for FAO member countries for the assessment of their inland fisheries (FAO 2018). The Roundtable covered two main themes:

i. Advice on an approach to develop a more comprehensive, credible, objective and replicable global assessment of inland fisheries; and

ii. Guidance on development of tools (which reflect the data-poor and constraints on human and financial resources that typify inland fisheries) that could be provided to member states seeking advice with respect to assessing the status of their inland fisheries

2. The lack of routine monitoring across a wide range of inland fisheries constrains FAO's ability to provide an indication of the status or health of global inland fisheries. This limitation covers both the effect of fishing activity, as well as that arising from anthropogenic drivers including climate variability.

3. With exception of some notable large-scale fisheries, monitoring of individual fisheries does not adequately reflect the state of inland fisheries across river basins or within national boundaries. The current global level of information available for analysis is national catch data, which is an aggregate of all national production data that are reported by countries. Unfortunately, trends of increasing or decreasing national catch provide little insight in the state or sustainability of individual fisheries and their stocks. It also does not provide an indication into whether declines in one fishery (or sub-national area) are offset by gains in another, unless sub-national information is available. Such limitations are even more serious in those basins with important recreational fisheries that may extract a large biomass that is not accounted by country statistics.

4. The first "Advisory Roundtable on the Assessment of Inland Fisheries" concluded that at the global, regional, basin and national levels the use of composite indices to measure respectively the pressures on inland fisheries and their adaptive capacity, using publicly available global datasets as inputs, could be an answer to this challenge.

5. At the specific fishery level, it is also clear that there is a need for a credible tool to assist inland fishery managers and policymakers to determine the state of a fishery. In many cases these fisheries are data poor and the responsible agencies have insufficient resources to conduct extensive stock assessment programmes. In order to explore the potential of applying length–based methods to assess inland fish stocks, a pilot investigation has been undertaken. These methods have already been tested in marine data poor fisheries but are not yet widely applied in freshwater fisheries.

6. This "Second Advisory Roundtable on the Assessment of Inland Fisheries", was convened in partnership with United States Geological Service (USGS), 25-27 November 2019, to review the outcomes of two assessment initiatives that have emerged from the first advisory Roundtable. That is a review of a threat assessment mapping framework developed by USGS and University of Florida and secondly an exploration of the use of length-based assessment methods for data-poor inland fisheries.

1.1 THE CHALLENGE OF ASSESSING GLOBAL INLAND FISHERIES

7. FAO does not have a framework or a standardized approach that provides a credible, objective and replicable assessment of the state of the world's inland fisheries and permits tracking these fisheries through time. This contrasts with marine fisheries where FAO routinely assesses the status of marine fish stocks. FAO thus monitors and reports to the FAO Committee on Fisheries (COFI) on the status and trends of 455 marine stocks covering about 80 percent of reported global marine catch. This assessment is based on stocks, which are routinely monitored, and only indicates the level of exploitation against a reference point (i.e. underfished, sustainably exploited, and overfished). However, this marine assessment does not consider effects of the underlying ecosystem effects or the state of the

system which sustains these fisheries, nor does it attempt to deal with any drivers other than that of the fishery.

8. Around 80 percent of the catch from inland fisheries are contributed by only 20 countries. These fisheries are located in 50+ major river basins, most of which are not routinely monitored and most of the exploited stocks remain to be defined. The importance of inland fisheries to some countries is undeniable, and even if their overall contribution to global catch volumes is low, their per capita dependency may be considerable. This is particularly the case in landlocked and low-income countries that are disproportionately reliant on inland fish. In other countries there may be regions at the sub-national level where such reliance is found.

9. Developing assessments and forecasting future sustainability is complex and tends to be rather localized. Development decisions are taken within political boundaries that are not necessarily ecologically meaningful. Using a landscape or basin level approach is probably the more reasonable and utilitarian way to consider inland fisheries at the global level, even if this requires aggregating a number of national assessments in the case of transboundary basins, particularly in those cases where the basins are severely fragmented by dams causing impacts on fisheries both down and upstream.

1.2. GLOBAL THREAT ASSESSMENT OF INLAND FISHERIES

10. The development of a robust assessment framework for inland fisheries (and the associated ecosystems/basins upon which they depend) will enable one more objective to be developed around the management of aquatic systems and the extent to which they can continue to provide their services. This framework needs to be sensitive to the divergent capacities and resourcing available to implement assessment, because so many of the countries, most dependent on inland fisheries, often have the least capacity in this regard.

11. A scalable system would further allow countries to use this approach to assess the status of their inland fisheries, predict future impacts and allow them to quantify the effect of management measures on fisheries for their own internal planning for future needs in food security, livelihoods, and recreation and investment, and would allow measurement of progress towards the Sustainable Development Goals (SDGs) and the Aichi biodiversity targets.

12. As a follow up to the 2018 "Advisory Roundtable on the Assessment of Inland Fisheries", the United States Geological Survey (USGS) and University of Florida, in cooperation with FAO, has developed a basin-level threat map for inland fisheries. This threat mapping combines global geographic information datasets, which relate to the drivers that influence inland fisheries. Combination of these data, using a nested modelling approach powered by supercomputers, generated a composite map that is intended to provide a visual (and quantifiable) indication of the relative level of threats to inland fisheries within a basin and its sub-basins.

1.3 LOCAL ASSESSMENT OF DATA POOR INLAND FISHERIES USING LENGTH-BASED APPROACHES

13. FAO promotes the Ecosystem Approach to Fisheries management (EAFm) as the most appropriate tool to manage inland fisheries. However, due to the nature of these fisheries, being highly diversified, complex, spatially dispersed, and hard to monitor and therefore frequently data poor, it is hard to identify indicators that will inform the managers about the performance of the management plan.

14. Such indicators should be able to detect the status of the population(s) in concern and require few types of data that can be obtained with low effort and cost and preferably be intuitive and easily understood by different stakeholders, potentially including those responsible for data collection and local fishers, who may have to implement, or comply with associated simple harvest control rules.
There is a need for assessment approaches that enable those working with inland fisheries at a local level to provide advice on the state of a fishery into management or advisory processes, especially where that may be driven primarily by fishing pressure, rather than other environmental drivers.

15. A study has been initiated to investigate the development of methods that could be used to inform the management of data poor inland fisheries. Length-based methods based on fish life history parameters have already been successfully tested on tropical marine small-scale fisheries, but less frequently in freshwater fisheries. This work has attempted to test empirical and model-based applications in inland fisheries.

2. PROCESS OF THE ADVISORY ROUNDTABLE

2.1 OVERALL PURPOSES

16. The overall purpose of the Second Advisory Roundtable was to review the development of assessment tools that can:

i. Be used as a framework to provide a global, objective assessment of inland fisheries (or specific inland fishery stocks) and their associated ecosystems/basins upon which they depend;
ii. Identify the threats, drivers and vulnerabilities that should be incorporated into the assessment;
iii. Assess adaptive capacity and options for amelioration or mitigation both within the fishery (fishery management) and outside (regulatory measures for ecosystem/basin/environmental management);
iv. Act as a replicable approach to measure/track change (i.e. improvement, deterioration, impact of mitigation measures, climate change, environmental degradation etc.); and
v. Provide indicators, which against reference points and based on limited data, can inform about the status of a specific fishery/stock/population, and thus be used to guide on management actions to be taken.

2.2. SPECIFIC OBJECTIVES

17. Based on the overall purpose of the Roundtable, the participants were requested to:

vi. Validate the theory behind the practical application of the approaches that have been tested;
vii. Identify the limitations of the methods proposed (in which situations can they be used and when not);
viii. Recommend improvements to the methods that will improve their applicability;
ix. Recommend additional case studies on different types of environments, other species with different life strategies and other fishing gears (taking into account the availability of data);
x. Identify alternative and more robust methods taking the typically data poor situation into account; and
xi. Suggest next steps.

2.3 PARTICIPATION

18. Experts with extensive experience from some of the most important inland fisheries regions around the world, concerned with the work of FAO as it relates to inland fisheries, were invited to the Roundtable. This included the fishery scientists who provided the data for the length-based assessments (the list of the participants is available in Annex II).

2.4. METHODOLOGY

2.4.1 THREAT ASSESSMENT MAPPING

19. The Roundtable reviewed several basin threat maps, which were developed from the USGS global threat assessment. The Roundtable was requested to review the threat scores for the basins and their sub-basins and reflect on how closely this aligned with their knowledge and perceptions of the state of inland fisheries in the basin.

2.4.2 GROUP WORK ON VALIDATION OF WEIGHTINGS

20. During the meeting, the outcomes of the preliminary work were presented, and the Roundtable participants were invited to cross-examine methods, assumptions and results. As part of the session in the assessment of threats to inland fisheries, a break-out group session was organized to solicit opinion from the Roundtable on relative weights for environmental, anthropogenic and climatic threats as drivers of inland fisheries for 24 basins around the world (Table 1). Ranking of five major threat categories was followed by scoring (0 to 1) of twenty-one sub-threats (Table 2).

Table 1: Basins covered by the groups of experts for review and rankings of threat impacts

Continent	Basin
Africa	Malawi, Victoria, Turkana, Okavango
North America	Laurentian Great Lakes, Mississippi-Missouri, Yukon, Colorado, Rio Grande, Columbia
South America	Amazon, Titicaca, La Plata
Asia	Tonlé Sap, Mekong, Irrawaddy, Ganges, Brahmaputra
Europe	Finland, Danube, Caspian Sea, Ob-Irtysh, Volga, South-eastern Sweden

Table 2: Major threats and sub-threats

Major threat	Sub-threat
Loss of connectivity	Channelization Dredging Dams Barrages, weirs, other barriers
Land Use	Deforestation, land degradation, sedimentation Mining Nitrogen runoff Phosphorous runoff
Climate change	Temperature increase/decrease/variability Precipitation increase/decrease/variability Predicted extreme weather events
Abstraction	Water abstraction for irrigation, agriculture Water abstraction for industry Water abstraction for urban, human consumption
Pollution	Sewage, organic runoff Pesticides, other chemical runoff Microplastics, pharmaceuticals, other pollution Aquaculture effluents
Other	Overfishing Disease Invasive species

2.4.3 LENGTH-BASED ASSESSMENT METHODS

21. Two main approaches to size-based assessment of data-limited inland fish populations have been tested. These include (1) the combination of simple empirical indicators and expert knowledge; and (2) the Length-Based Spawning Potential Ratio (LB-SPR) model. An overview of both these methodologies was presented, with the opportunity for questions and general discussion on theory and applications.

22. Four international case studies using the Length-Based approaches were then presented and reviewed by the Roundtable. The national experts who had provided data for each case study were present, and this allowed reliable local insight in interpretation of the analyses and results.

23. Discussion sessions then provided critical feedback on the approaches used in relation to the specific characteristics of each of the case studies. That allowed the elicitation of concerns, and caveats

in the application of both assessment approaches. The group subsequently assimilated the two case study approaches into a preliminary concept for a flexible and holistic rapid assessment framework for data-limited fisheries.

3. A GLOBAL INLAND FISHERIES THREAT ASSESSMENT

24. As a follow up to the Advisory Roundtable on the Assessment of Inland Fisheries, USGS and the University of Florida in cooperation with FAO have developed a basin-level threat map for inland fisheries. This threat map is working towards a scalable and reproducible assessment of global inland fisheries based on potential pressures on inland fisheries.

3.1 THREAT MAPPING

25. This threat-mapping combines global geographic information datasets, which relate to the drivers that influence inland fisheries. Diverse data types and sources were combined using geospatial modelling techniques and threat-mapping theory (Figure 1). Combining this data and using a nested modelling approach powered by supercomputers generates a composite map that is intended to provide a visual (and quantifiable) indication of the relative level of threats to inland fisheries within a basin and its sub-basins.

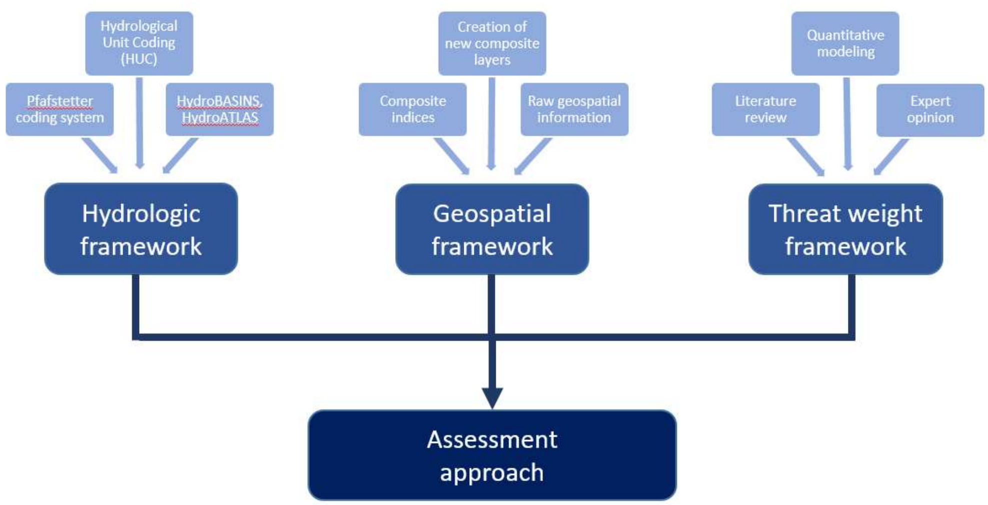


Figure 1: This assessment uses a hydrological, geospatial, weighted threat index approach

26. Pressures that are relevant to inland fisheries were mapped within a hydrological framework for improved examination of fisheries inclusive of their watersheds and influences from both land and water. Environmental and climatic data are summarized at the smallest sub-basin unit (mean area = 130 km2) up to the largest basin (mean area = 100 000 km2).

27. Over 45 sources were screened to identify the pressure variables used in the modelling, of which more than 40 datasets were finally chosen. From these datasets, eight usable variables were derived. The spatial level of detail for these variables was not uniform, with some variables available down to very high degrees of resolution and other less so. Variables were available in a combination of formats including spatial data, line data (e.g. rivers, roads), polygons (e.g. boundaries of lakes, basins, countries) and point-data (e.g. dams). All data were assigned to the respective hydrobasin and sub-hydrobasin.

28. The scalability of the summarized data allows users to examine the variables that place pressure on inland fisheries for a basin relative to basins globally, and then access sub-basin summaries for their desired area of interest or management. Applying weights to the identified variables and sub-variables

allows the determination of their relative influence on the overall threat score. A mixture of data sets was combined into the model, covering line data, polygons, point data and density-related data. The output is a composite map that is intended to provide a visual (and quantifiable) indication of the relative levels of threat to the potential of the water body to support inland fisheries or aquatic biodiversity within a basin and its sub-basins. The threat-map can also be considered a proxy for the relative combined anthropogenic and natural pressures on a specific basin or sub-basin supporting fisheries (Figure 2), noting that, up to a point, some of these may increase fishery productivity rather than constrain it.

29. The spatial approach uses a hydrologic framework more relevant to inland fisheries, rather than gridded, country-level frame. This therefore considers potential pressures arising across landscapes rather than limiting them to those occurring within water bodies. The data processing calculates values per basin area, as well as upstream, for any raster, polygon, and point data. The summarized data is organized into ten scalable, nested hydrological basin units. These ten sizes of hydrological units allow for application of the mapping from very local up to the global scale.

30. The approach has several advantages and improvements over previous global assessments of freshwaters. It integrates threat results from global studies and modelling to produce the best possible threat score. Threat equation weights are derived from a systematic literature review of major basins, a literature synthesis of global studies, expert opinion, and numerical approaches involving machine learning in boosted regression trees and multivariate linear regression analysis. The application of an iterative weighting approach creates a composite threat index.

31. This work is an ongoing programme under the USGS and upon completion, the threat mapping GIS layer will be freely available through ScienceBase and other open source information systems. As an open-source scientific database, ScienceBase will serve as the data repository, a catalogue of code and data processing documentation and a link to acquired datasets and relevant collaborations. It is expected that at the aggregated, global scale, data layers would only change significantly over a five to ten-year period, and this would be the typical time frame for periodic updates on a global state of threats to the inland fisheries.

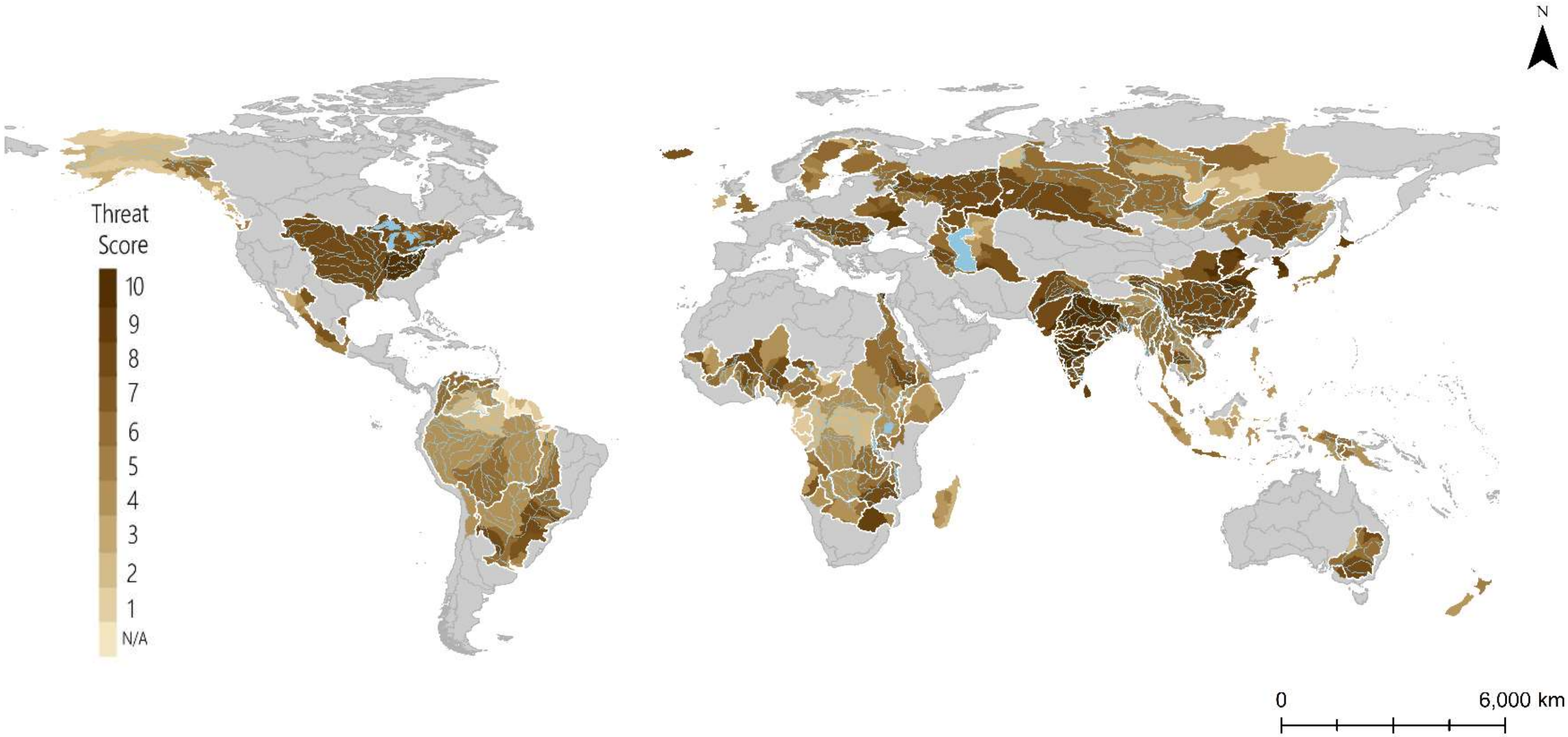


Figure 2: Global “status map” based on the interaction of pressure variables at basin level for the key basins that support substantial inland fisheries (note that the border lines represent hydrosheds, the basins outlined in white represent approximately 76 percent of global inland fisheries catch).

Source: Unpublished data US Geological Survey, Land and Water Lab at the University of Florida. Map conforms to United Nations World map, [February 2020].

32. An important feature of these threat maps is that they are scalable, ranging from the global map (Figure 2) through to basin and sub-basin scales (Figure 3 and Figure 4). This allows fisheries and environmental managers to examine threats and drivers at the level, which is most appropriate to their management plans and supports an ecosystem approach to fishery management.

33. The mapping in Figure 2 identifies areas that are most prone to negative impacts as a result of pressures from increased eutrophication, high population density, pollution, land use and habitat fragmentation. It can provide insight as to where effort should be directed to understand the consequences of these pressures, especially if the area has a high catch or is of significance for aquatic biodiversity. The preliminary results of the analysis covered 87 identified basin areas, which produce 95 percent of the global inland fish catch (Table 3).

Table 3: Threat scores of basin areas that support inland fisheries

Threat score	Number of basins	Share of global inland fish catch (%)
1–3 (low)	2	< 1
4–5 (intermediate)	37	47
6–7 (moderate)	33	38
8–10 (high)	15	10
Total	**87**	**95**

34. At the basin scale, the highest threat scores facing inland fisheries arise from a combination of loss of hydrologic connectivity, water abstraction, low gross domestic product and high population density (this will tend to drive fishing for food), land-use change and associated runoff. These threats may be more relevant to riverine and floodplain systems rather than large lake systems.

35. Only two of the basins score below 3, reflecting either low population densities and relatively low agricultural pressures or regions where environmental management places some limits on the threat to freshwater environments and their fisheries. However, these two basins produce a negligible amount of inland fish.

36. The majority of the world's inland fishery catch comes from basins that score 4–5 (47 percent) or higher at 6–7 (38 percent). The latter category represents some of the world's most productive inland fisheries that have rather high threat scores underlining the fact that, in these basins, high population densities and nutrient loadings, coupled with abundant water resources, might drive their productivity. Only 10 percent of global inland fish catch comes from the basins with the highest threat scores.

37. The threat maps may be more representative of fisheries in large, shallow lakes (e.g. Tonlé Sap), and riverine floodplains, wetlands, deltas and reservoirs, than those in very large water bodies (e.g. Caspian Sea, Laurentian Great Lakes, Lake Malawi, Lake Tanganyika, Lake Victoria). This may be due to the high residence time and slow water turnover of large lake systems allowing them to absorb or accumulate impacts through processes that occur over a period of many years before reaching a tipping point. Also, the geomorphic complexity of large lakes may limit surrounding impacts to only particular areas. Hence, a "low" impact basin could surround a large lake where significant eutrophication effects are seen (e.g. Lake Victoria). Such water bodies will require a separate threat analysis for the water body itself.

38. Figure 3 presents basin-level threat maps for three important inland fisheries in Asia and Africa. The sub-basin disaggregation shows how different parts of a basin may contribute to its overall threat level. The different levels may be due to high concentration of impacts in some areas, but not others. It emphasizes that not all parts of a basin are affected in the same way and this has implications for both fisheries and biodiversity in each of these sub-areas.

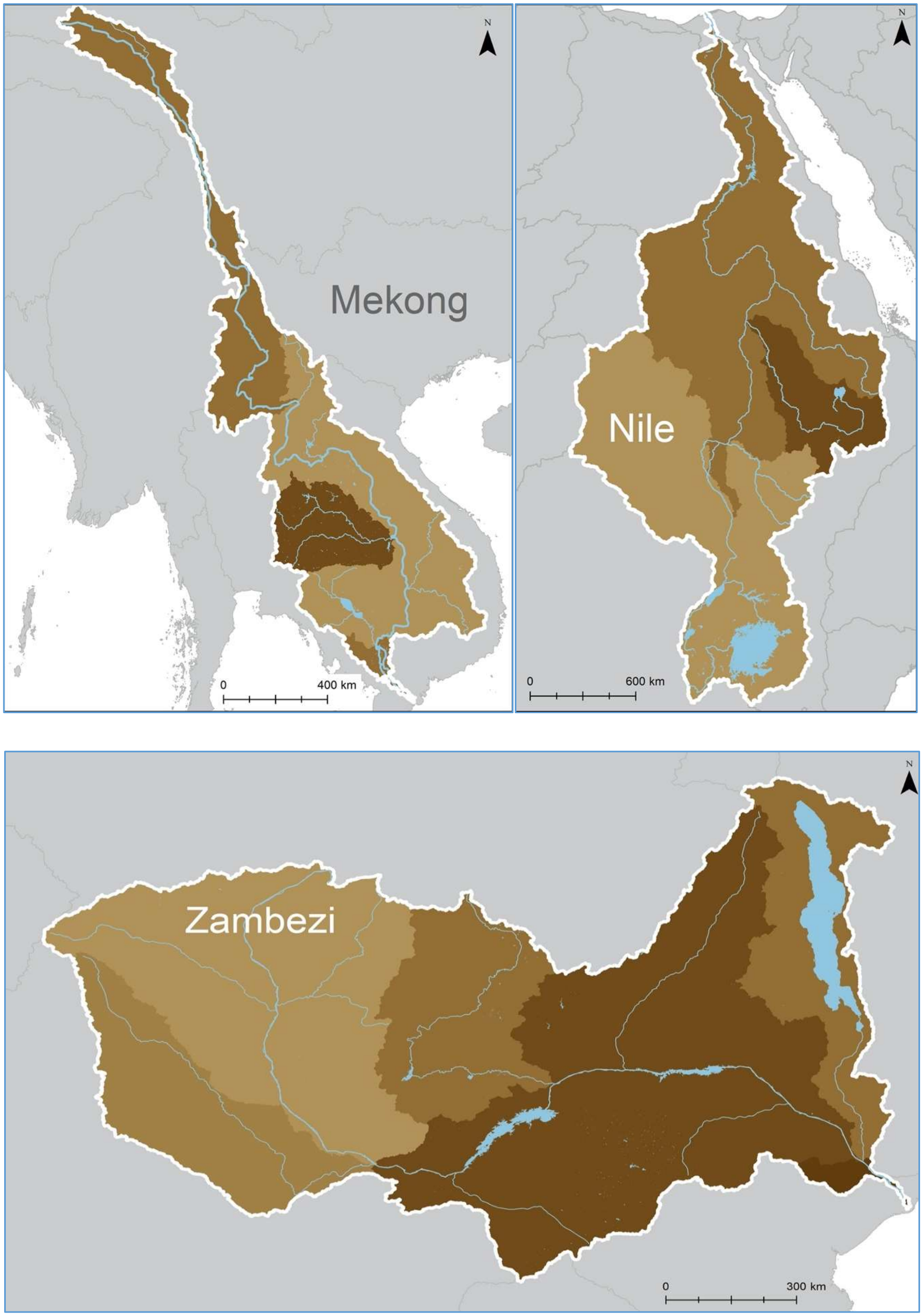


Figure 3: Basin-level threat maps for important inland fisheries a: Mekong river basin in South East Asia; b: Nile river basin in Africa and c: the Zambezi river basin in Africa.
Source: Unpublished data US Geological Survey, Land and Water Lab at the University of Florida. Map conforms to United Nations World map, [February 2020].

39. An important feature of these threat maps is that they are scalable, ranging from the global map (Figure 2) through to basin and sub-basin scales (Figure 3 and Figure 4). This allows fisheries and environmental managers to examine threats and drivers at the level which is most appropriate to their management plans and supports an ecosystem approach to fishery management.

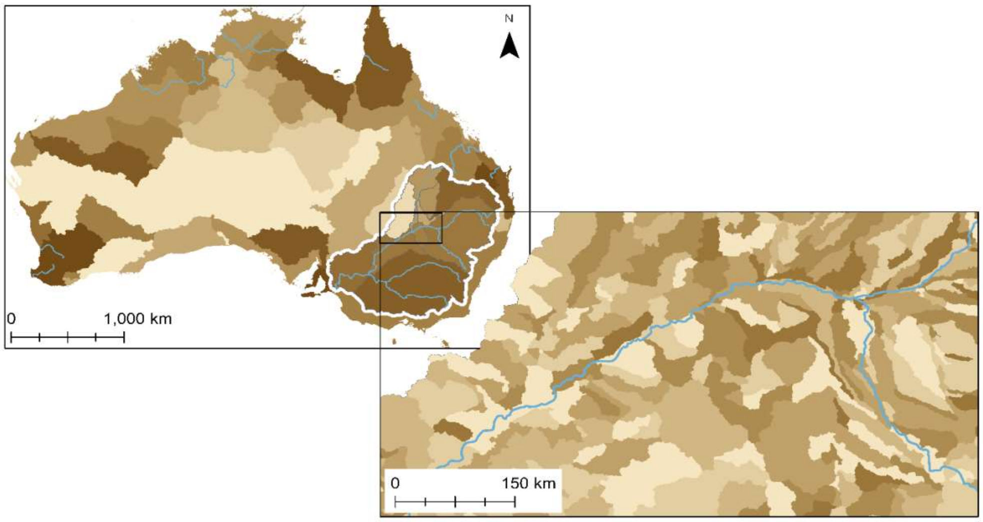


Figure 4: A mock-up example of how the maps of the threats will be available at different scales from basin level down to subsidiary basin levels, which can support local planning processes.
Source: Unpublished data US Geological Survey, Land and Water Lab at the University of Florida

40. The advantage of this approach is that it uses global, publicly available data, thus allowing coverage of countries that may have very limited capacity to collect and report data to FAO. The interpretation of the maps can be greatly enhanced by linking this to local knowledge and field data collection. Linking the threat maps to fishery data at a sub-national level will enable more detailed national analysis and planning, especially pointing to areas where there is a need for greater understanding of primary threats and their relationship to fisheries production and fish biodiversity. This would enable national fishery agencies to identify important inland fisheries (or aquatic biodiversity) that are at risk and prioritize appropriate fishery monitoring and management interventions.

3.1.1 GROUP WORK ON WEIGHTINGS OF VARIABLES

41. A group activity was organized to compare expert opinion (of the Roundtable) with the results from a literature review and weightings for major variables used in the model and to inform the process of including localized expert opinion of threats in the global model. Total scores for each threat category were summed, averaged and ranked relative to one another from lowest threat (1) to greatest threat (5) (Table 4, Table 6). The same metrics were calculated for sub-threats (Figure 5).

Table 4: Ranking of the relative importance of main threat variables to inland fisheries (1 = lowest threat, 5 = greatest threat). The numeric approach included population factors as an additional threat; as such an additional sixth rank number was included below.

Method	Connectivity	Land Use	Climate Change	Water abstraction	Pollution	Population
Literature	3	5	1	4	2	N/A
Numeric	5	5	4	3	1	2
Expert	3	5	1	2	4	N/A
Average	3.7	5	2	3	2	1

Table 5: The relative weights assigned to the different major threat variables

Method	Connectivity	Land Use	Climate Change	Water abstraction	Pollution	Population
Literature	0.20	0.26	0.12	0.26	0.15	N/A
Numeric	0.31	0.34	0.18	0.09	0.03	0.05
Expert	0.20	0.28	0.12	0.17	0.23	N/A
Average	**0.24**	**0.29**	**0.14**	**0.17**	**0.14**	**0.02***

*residual

Table 6: Continental breakdown of expert review rankings (1 = lowest threat, 5 = greatest threat) for each threat category

Continent	Connectivity	Land Use	Climate Change	Water abstraction	Pollution
North America (n = 6)	4	5	2	3	1
South America (n = 3)	3	5	2	1	4
Africa (n = 4)	1	5	2	4	3
Europe (n = 6)	4	2	1	3	5
Asia (n = 5)	3	5	1	2	4
Average (n = 24)	**3**	**5**	**1**	**2**	**4**

Table 7: Continental breakdown of expert review weights (0 = no influence on total threat, 1 = 100% influence on threat weight) for each threat category

Continent	Connectivity	Land Use	Climate Change	Water abstraction	Pollution
North America (n = 6)	0.23	0.19	0.20	0.23	0.15
South America (n = 3)	0.14	0.36	0.13	0.05	0.32
Africa (n = 4)	0.08	0.42	0.10	0.22	0.18
Europe (n = 6)	0.30	0.17	0.03	0.14	0.36
Asia (n = 5)	0.20	0.38	0.11	0.14	0.17
Relative average (n = 24)	**0.19**	**0.30**	**0.11**	**0.16**	**0.24**

42. Overall comparison of weightings of the expert group and those weights derived from the literature review and the machine-learning in the model provided some close convergences as well as striking dissimilarities. Connectivity or fragmentation problems and land use were the highest weighted variables, with close agreement between literature and expert opinion (Table 4 and Table 6). Literature and expert opinion disagreed on the relative importance of water abstraction and pollution and this was reflected in the relative weights assigned (Table 5 and Table 7). Whereas some threats may have a more global influence and therefore explain a close agreement, others depend on local or regional basin characteristics.

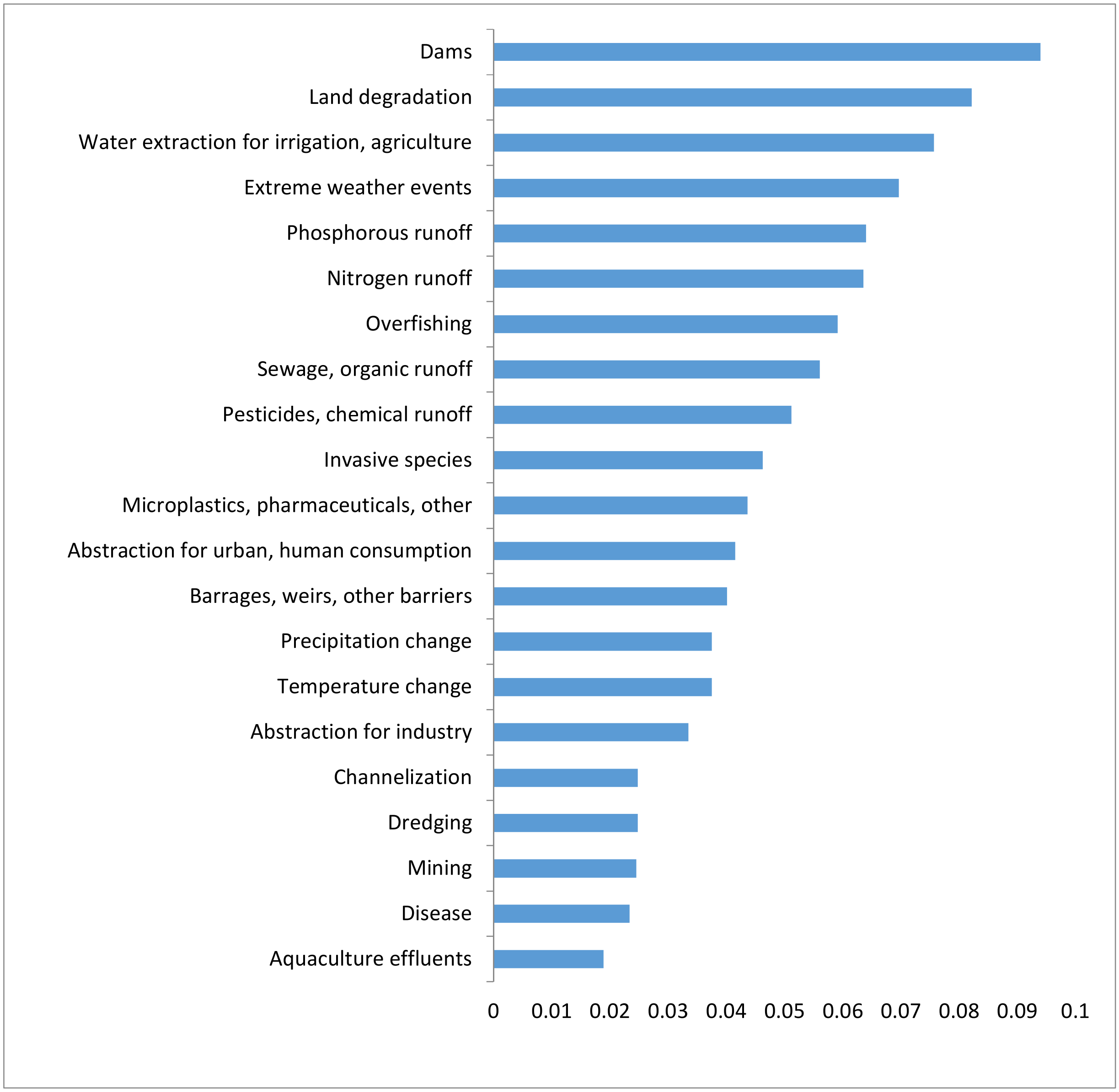
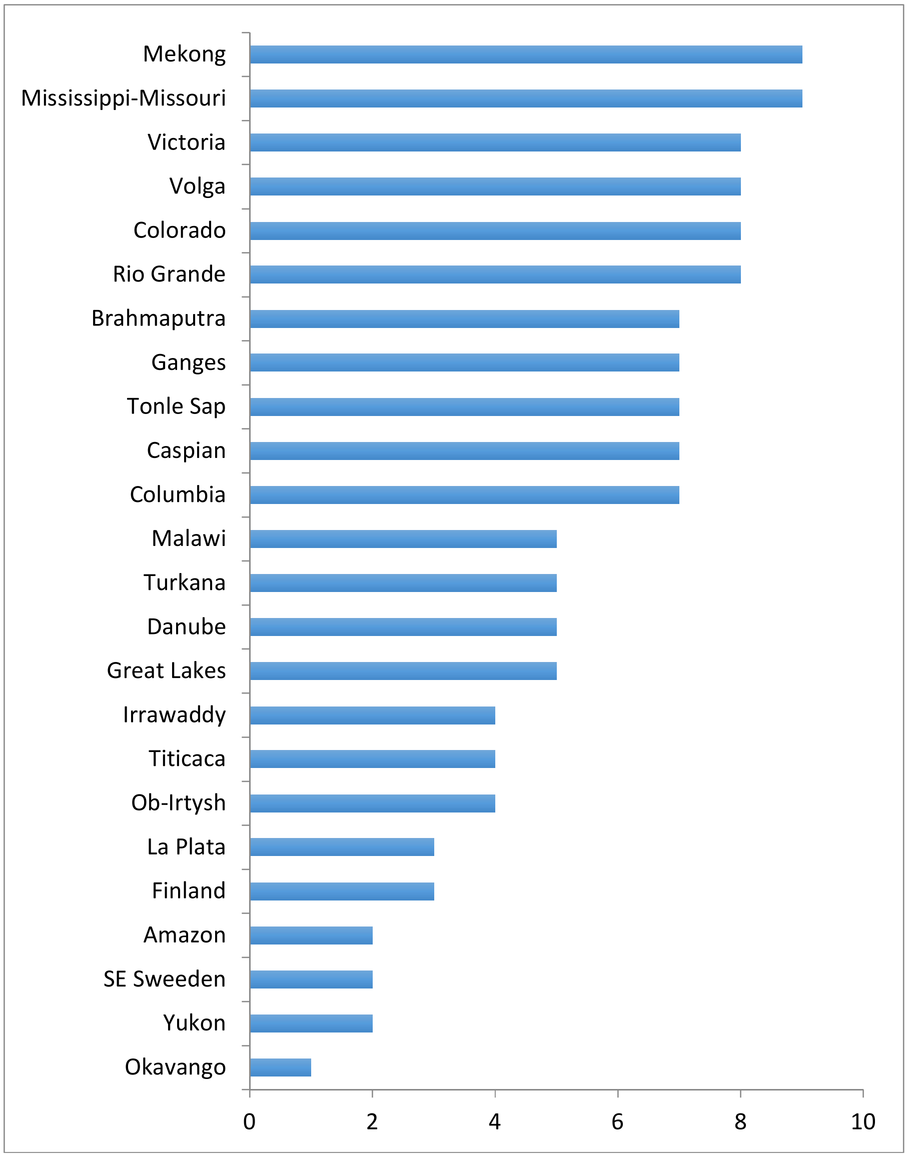


Figure 5: Expert opinion of the relative influence of each sub-threat globally

3.1.2 GROUP WORK VALIDATING RESULTS OF INDIVIDUAL BASIN ASSESSEMENTS

43. Each group of experts worked with the region they were most familiar with and considered the threat assessment results for several basins and sub-basins. This was used to provide overall expert feedback on the results arising from the model presented below (Figure 6).

Figure 6: Overall perceived threat by expert review of basins (1 = least threatened, 10 = most threatened)



3.2 ROUNDTABLE DISCUSSION AND CONCLUSIONS ON THE THREAT ASSESSMENT

3.2.1 LIMITATIONS TO THE ASSESSMENT FRAMEWORK DEVELOPMENT

44. The assessment framework was developed within a short timeframe (~6 months) with limited staff time (1-2 researchers) putting constraints on the capacity to develop the analysis at global scale and there are consequently some inherent limitations, including:

1) Generalizations in the definitions of threats across systems (e.g., rivers, wetlands) and for specific species;
2) Exclusion of threat mapping of individual water bodies (including large lakes);
3) Omission of distance-weighted and nutrient cycle modelling of land influences on water bodies; and

4) Temporally discrete - latest available data only, no past or future (except climate) scenarios.

45. This analysis uses only global, rather than basin specific weights, though the methods can be replicated at the basin level with future improved data resolution. This approach considers only natural areas (no aquaculture) and does not consider seasonal or variable landscape dynamics. For some datasets there are issues with poor data quality, quantity and disparate availability at the global level (especially for fish catches). Poor data resolution, organization, and quantity often constitute peripheral and indirect threats as proxies. Inherent interactions also exist between variables (e.g., cropland and pollution).

46. A final observation of the approach is that whilst it combines a range of threats that impact inland fisheries, it is not a vulnerability assessment, as it does not include sensitivity analysis and adaptive capacity measures.

47. The Roundtable noted that threat assessment might not reveal effects that are transferred between sub-basins, particularly upper and lower reaches of the same river basin. It was acknowledged, however, that threat assessment is a combination of threats, and in most cases the experts were considering single threats such as interference with water flows.

48. The Roundtable also observed that the assessment process assumes that low GDP and high population pressure will tend to drive fishing effort. While this assumption may prove correct for many regions of the world, it breaks down in situations where there is strong cultural resistance to eating fish and in countries with high apparent GDP (e.g. from oil wealth), where poor rural households continue to access inland fish regularly for their livelihoods.

49. The Roundtable considered that the entire basin from source to sea should be included in the analysis because each part of the basin may support different fisheries and be subject to different threats. Each part of the basin should therefore also be analyzed separately because the vulnerability of the fisheries must therefore take the socio-economic characteristics of the fisheries and their spatial distribution into consideration.

50. The Roundtable recommended that in order to analyze large complex basins, it will be necessary to correlate the analysis with other sources of information, including expert knowledge.

3.2.2 INLAND FISHERY STATUS OR BIODIVERSITY?

51. The threat assessment combines a range of possible threats to fish and aquatic life. The Roundtable agreed that in most cases, the threat acts in the same direction, regardless of whether one is looking at threats to inland fishery production, recreational fishing or aquatic biodiversity. However, in the case of nutrient runoff, this might act positively on fish production (up to a point), but negatively on biodiversity (changing water quality, trophic relationships and species composition).

52. A complication arises when there are several different fisheries operating in the same body of water and when they are responding differently to the drivers, or, responding to different drivers (e.g. eutrophication). As the assessment is not primarily directed at biodiversity conservation, (i.e. mainly as food fisheries, although there is some overlap), it would be useful if the model could take into consideration the life history of the fish or incorporate differential purposes of the fisheries. The issue is whether a basin is providing the environmental conditions that are conducive for fish.

53. The Roundtable considered whether the assessment might need a system for differential weighting according to either the purpose of the fishery (food production, conservation of biodiversity, or recreational fishing), or the environment (arctic, temperate, tropical etc.) within which it operates.

3.2.3 ADJUSTING WEIGHTING TO ACCOMMODATE MAJOR DIFFERENCES BETWEEN LATITUDES

54. Overall, the Roundtable felt that the assessment of threat intensity seemed to be weighted towards a northern hemisphere perspective on threats such as connectivity. While, in the case of Africa, these threats were considered relatively less important as the fisheries were largely based around large lakes and other water bodies, and therefore less driven by migratory fish species (the model for example accorded high threat levels to the Ethiopian Highlands and the South African Vaal basin, neither of which has long distance migrating species driving fisheries). The Roundtable noted that this model was built on a base created for the USA and it might thus be more responsive to North American basins and inland fisheries in temperate latitudes than to fisheries in tropical and sub-tropical regions.

55. The Roundtable further considered that it was important to assess if weightings could capture context dependency (i.e. in Africa/Asia, land use/deforestation/population density may have a greater influence than connectivity about impacts). It was also agreed that population density was probably still the most influential/most evident indicator of impact because most people are still engaged in primary production systems (agriculture and fisheries), and there is relatively little industrialization or agricultural intensification.

56. As noted above, there may be some instances where a threat acts positively or negatively, according to the context. These relationships may also have differing influence according to the latitude of the fishery. Several examples in the literature show that climatic differences between northern and southern hemispheres due to oceanic currents, orographic effects, winds circulation, etc., may preclude making global generalizations related to waterbodies production and ultimately fisheries performances. For example, a certain level of nutrient runoff may have severe influences on temperate and arctic waters yet be quite benign in some tropical systems.

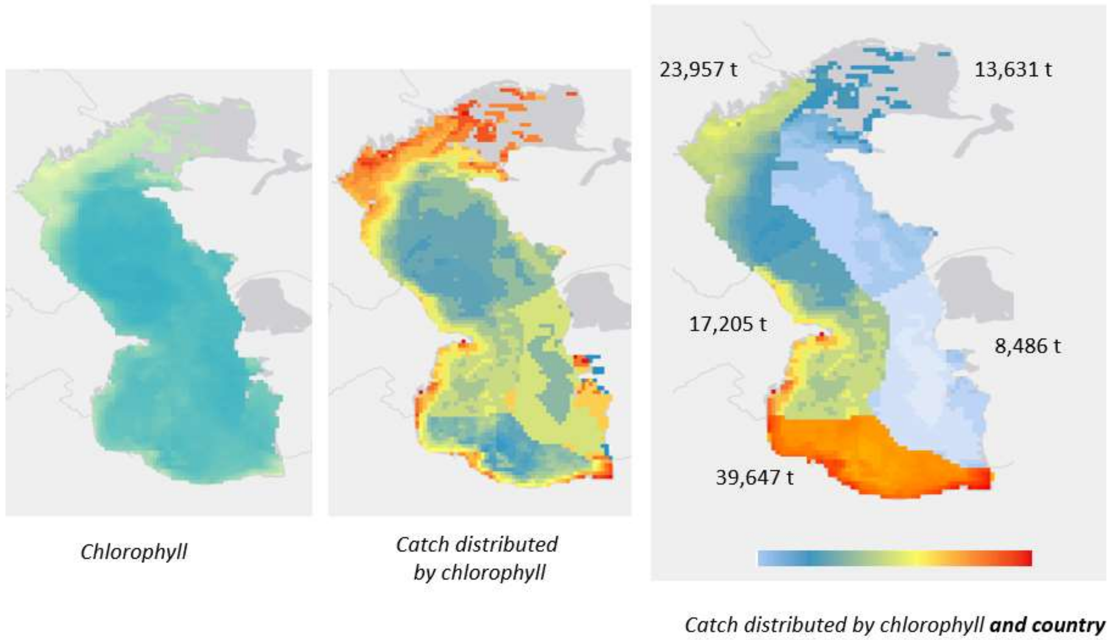
57. Overall, this indicates a need for due consideration of the effects of weights, of threats and the possibilities of having some adjusted rules for weighting to reflect differences between arctic, temperate and tropical systems. The conclusion was that there is some merit in having a procedure for applying different weights. This should not be arbitrary and on a case by case basis but would benefit from having some rules that will accommodate cases where there is a strong divergence in the effect of a specific threat.

3.2.4 SPATIAL SCALES

58. The Roundtable noted the limitations of using the influence of the surrounding basin threats to the fishery of a large water body such as the Caspian Sea, which will respond only slowly to the overall conditions in their basins due to their buffering capacity and internal processes. This echoed the finding of the North America group (above) when considering the Laurentian Great Lakes case example, and that of the Africa group in relation to the large African rift lakes.

59. For those reasons, the Roundtable recommended that a dedicated threat assessment for those water bodies may be necessary. The allocation of threats or productivity could be undertaken using remote sensed data (e.g. Chlorophyll, a morpho-edaphic index for nutrients and other sources for pollution/sediments). This might also be used to indicate fish catches for individual countries within a large waterbody (theoretical example provided in Figure 7). It was further noted that small reservoirs and lakes would respond to the conditions in the basin and that the basin threat score would be an acceptable proxy.

Figure 7: Example of the use of Chlorophyll - a distribution to apportion productivity and fish catch of the Caspian Sea



60. The Roundtable also commented that the model appeared to work better with flowing water/river basins rather than large water bodies and morphometric characteristics could produce deviations from the model. The specific and more localized threats from cities or irrigation and other land uses within basins was noted by the Roundtable. The Roundtable concluded that local expert knowledge will be required to produce validations at the same spatial scale as produced by the model.

3.2.5 IMPROVEMENTS AND FUTURE STEPS

61. The Roundtable considered how the current model could be used to inform understanding of global status of inland fisheries and how it may be used as a tracking approach.

62. The current purpose of the analysis is to assess the present status (i.e. establish a baseline) of the pressures on inland fisheries. It is not designed to predict or assess future vulnerability. A longer-term vision may be to develop a global index for key indicator inland fisheries, where the most significant inland fisheries can be tracked on a routine basis.

63. The Roundtable considered the need to incorporate market and economic drivers in the model. In the first Roundtable, the value of the fishery was included as a third dimension in the assessment to indicate economic or social importance. The Roundtable agreed that this was a limitation on a global approach as the valuations between food security, biodiversity and economic values of food or recreational would constrain a unified approach.

64. The Roundtable noted that the inability to find a common reference point for all basins would be the major constraint, for example:

- The Mississippi River produces a lot of protein, but this is not being exploited as food. If the Mississippi were in Africa it would get a different score.
- The Okavango has low productivity but has high conservation value.

- River systems in some countries have been heavily transformed, but still support recreational or food fisheries.

65. The Roundtable emphasized that it will always be a management decision what the objectives of fisheries management are, and thus how values are assigned to the fisheries. On the other hand, some elements of governance principles could be included in the accompanying expert validation of the model results. An example of how governance can be incorporated into an assessment are the fisheries performance indicators, which have been tested in the Madeira River fishery. This approach incorporates elements of economics, fish catch, technology and governance (e.g. https://www.fpilab.org/fishery-performance-indicators/).

66. The Roundtable agreed that the framework should be peer reviewed to confer scientific credibility. In order to better understand the framework, evaluate whether it is scientifically robust and make recommendations on any needed adjustments, it will be necessary to know the internal components and underlying assumptions of the modelling and geospatial processes. Time limitations of the Roundtable prohibited a detailed discussion of the underpinnings of the framework; however, such evaluation by experts should be considered as a future action item.

67. The Roundtable questioned how the model would be able to handle uncertainty. One aspect of this was that it currently uses mixed data from different years thus it does not provide a single baseline year but a composite picture over a period of years. This is sufficient to give a first approximation and would be improved as more geospatial data becomes available. The Roundtable did acknowledge that the rate of change of many of the variables means that this is probably not a major constraint with the current application. One aspect where major changes occur in a very short time span is the development of major dams and the consequent impact on water flows, connectivity and a range of other environmental variables. Current geospatial data associated with dams include the locations of planned dams, which could be incorporated into the framework.

68. The model needs to be trained considering what drives production in different parts of the world and rerun for important basins with a rule set. We could test the model on specific fisheries where good data is available. That would create more confidence in the model. Level 5 polygons (Hydrobasins) (which include lakes with an area ≥ 250 km^2) would, in most cases, provide the resolution that would allow for enough detail to carry out a meaningful assessment of the relevant inland fisheries. This level encompasses large enough areas that align with fish catch and well-known basin names, while honing-in on areas of importance (e.g. Lake Victoria within the Nile). It also reduces some of the noise that inherently comes in larger basin areas from extraneous threats. Each basin must be analyzed separately, and a short text for each basin explaining what the management objectives are should be included, so that all the outcomes can be combined in the end. A list can then be made of the number of basins at respectively low and high threat levels and how many are threatened.

69. The basins that have been analyzed thus far were selected based on the study by Ainsworth, Funge-Smith and Cowx (2018). The Roundtable expressed concern about the objectivity and asked for a more random approach that would be more objective. However, people tend to be biased, which is why we need a machine to run the assessments, and ultimately incorporate both (i.e. expert opinion scoring plus numerical modelling scoring).

70. The Roundtable agreed that the model framework developed by this initiative offers much opportunity and made the following recommendations for its further development:

1) Rerun the model with some adjusted weights based on rules for latitude/altitude and developed/developing status
2) Consider incorporating:
    a. Landscape hydrology modelling, including the status within very large lakes; and
    b. Microwave imagery for detecting habitat changes.
3) Apply a more comprehensive model validation process:

   a. Review several basins in detail with a multidisciplinary team;
   b. Identify model variables that are most influential in the analysis; and
   c. Several of the selected variables may interact, consider a correlation analysis.
4) In the longer term, develop an automated system to update datasets into the threat map as they become available.
5) Develop a user interface tool for fisheries managers:
   a. Enable them to delineate their fishery area;
   b. Allow them to enter their own data; and
   c. Allow them to receive a customized threat score plus threat summaries.

4. SELECTING SOME KEY INDICATOR BASIN FOR MONITORING

70. The lack of routine monitoring across a wide range of inland fisheries constrains our ability to provide an indication of the status or health of global inland fisheries. This limitation covers both the effect of fishing activity, as well as that arising from other anthropogenic drivers including climate variability.

71. Except for some notable large-scale fisheries, monitoring of individual fisheries does not adequately reflect the state of inland fisheries across river basins or within national boundaries. The current global level of information available for analysis is national catch data, which is an aggregate of all national production data that are reported by countries. Unfortunately, trends of increasing or decreasing national catch provide little insight in the state or sustainability of individual fisheries and their stocks. It also does not provide an indication into whether declines in one fishery (or sub-national area) are offset by gains in another, unless sub-national information is available.

4.1 ALLOCATING INLAND FISHERIES BY BASINS

72. The Roundtable recognized the importance of considering the environmental heterogeneity that often exists among basins and sub-basins and that ultimately determine fisheries characteristics. Allocating national, inland fishery catch data into basins and sub-basins and large waterbodies, therefore provides a more realistic picture of the areas where inland fisheries are conducted (Figure 8). This also provides an indication as to the possible selection of key inland fishery basins and water bodies for a global inland fishery assessment.

73. Combining the information from the basin threat assessment with the inland fishery catch mapping could also be used to select and track some key inland fisheries as indicator fisheries. Using the indicator fisheries could provide a basis for a replicable assessment of the changes in global inland fisheries production.

74. Such basin assessments of inland fisheries could initially be supported by holistic fishery evaluation approaches, aiming at capturing fishery status without requiring intensive sampling programmes.

75. The Roundtable recommended that in order to establish a representative list of inland fisheries to monitor, the following considerations would need to be considered:

- Determine and prioritize which basins to invest time and effort into trying to assess, using a matrix to score:
  - The importance for inland fishery production, recreational fishing or biodiversity or conservation.
  - The management purpose of the fishery or water body being monitored (food provision, recreation or biodiversity), as this can influence the value judgements made concerning whether a water body is threatened or performing well.

- The regional or national representativeness.
- Ensure an adequate mix of water body types: lakes, rivers, floodplains and small water bodies, swamps/wetlands and man-made reservoirs.
- Represent a reference system against which other more impacted fisheries can be compared.

A first level breakdown of 95 percent of the world's inland fishery catch can be attributed as per Table 8.

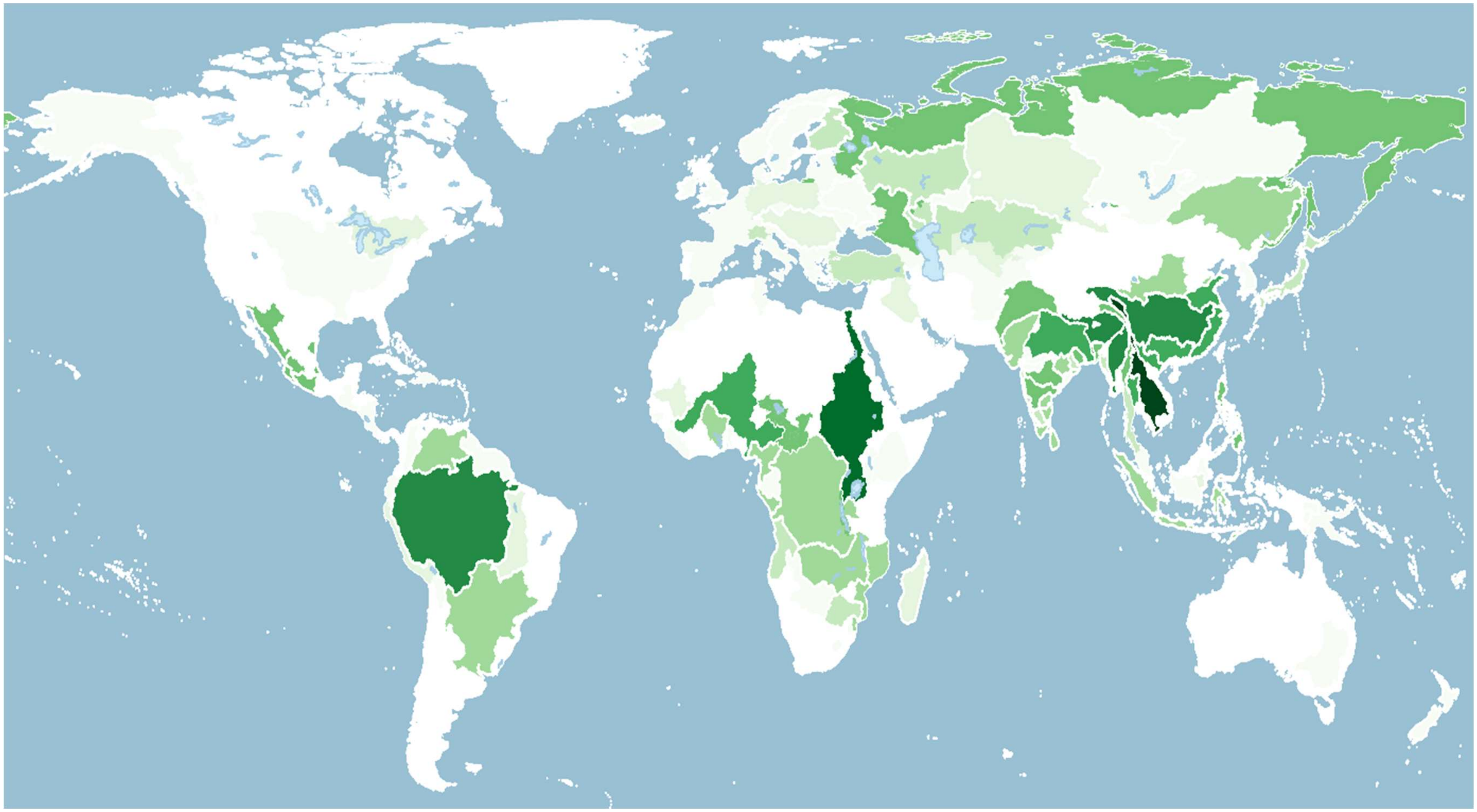


Figure 8: Estimated inland fishery catch allocated to major hydrologic regions and the river basins in which it was produced, expressed as a percentage of the global total inland catch. Note that this does not include retained recreational catches. (White = no significant catch; lightest green = <0.1% and darkest green = 14-18% of the global total inland fishery catch).

Source: Adapted from: unpublished data, Hull International Fisheries Institute; FAO FishstatJ. Map conforms to United Nations World map, [February 2020].

Table 8: The major hydrological basins that provide 95 percent of global inland fisheries catch

River basin	%	River basin	%	River basin	%
Mekong	15.15	Caspian Sea	0.76	Ob	0.14
Nile (incl. Lake Victoria)	9.69	Huang He (Yellow)	0.71	Laurentian Great Lakes	0.13
Irrawaddy	7.80	Ziya He	0.71	Tocantins	0.11
Yangtze	6.82	India East coast	0.68	Mahakam River	0.10
Brahmaputra	5.51	Orinoco	0.59	Kalimantan	0.10
Amazon	4.26	Zambezi (excl. L. Malawi/Shire)	0.57	India NE coast	0.10
Ganges	3.50	Mahanadi	0.52	Korean peninsular	0.09
Xun Jiang (Pearl)	3.27	Volta	0.50	Ural	0.09
China coastal basins	2.74	Gulf of Guinea	0.49	Narmada	0.09
Hong (Red River)	2.46	Amur	0.49	Dnieper	0.08
Chao Phraya	2.37	Sabarmati	0.46	Tapti	0.08
Niger	2.12	Sri Lanka	0.44	Sweden basins	0.07
Yasai West Bengal	1.64	La Plata	0.42	Mississippi - Missouri	0.06
Indus	1.56	India South coast	0.41	Mahi	0.05
Philippine archipelago	1.32	Thailand Southern peninsular	0.34	Ouémé	0.04
Salween	1.27	Cauvery	0.29	Malaysian Peninsula	0.04
Krishna	1.22	Volga	0.28	Magdalena	0.04
Godavari	1.20	Angola, Coast	0.25	Lake Turkana	0.03
Lake Tanganyika	1.08	India West coast	0.23	Yenisey	0.03
Sumatra	0.99	Bay of Bengal NE coast	0.23	Sepik	0.03
Java – Timor	0.99	Finland basins	0.23	Lena	0.02
Sulawesi	0.99	Brahamani	0.22	Murray - Darling	0.02
Mexican basins	0.99	Japan	0.21	Ogooué	0.02
Lake Chad	0.96	Limpopo	0.20	Fly	0.02
Congo (excl. L. Tanganyika)	0.94	Senegal	0.20	NE South America, S Atlantic Coast	0.01
Pennar	0.94	Madagascar	0.17	Okavango	0.01
Lake Malawi/Nyasa	0.92	Danube	0.16	New Zealand	0.01

4.2 CONCLUSIONS ON LINKING THREAT ASSESSMENT TO INDICATOR BASINS

76. The Roundtable concluded that the value of mapping threats is that it enables a downscaled evaluation of threats to inland fishery food production and biodiversity at the basin and sub-basin level, as well as prioritizing needs for ecosystem restoration and improved conservation.

77. The inland fishery assessment could also be compared with existing assessments undertaken by integrated water management frameworks or basin authorities on the environmental status of these basins (noting that in most cases fisheries assessments are not undertaken by these bodies). The Roundtable recognized the need to consider the geographic and climatic context in which the different types of fisheries take place as a key factor that could influence threats assessment on a global scale.

78. Linking an understanding of the state of the selected inland fisheries to the global threat map would also provide a baseline and a means to report meaningfully on progress towards international goals such as the Aichi Targets on inland fish stocks, and support to the SDGs through recognition of the importance of inland fisheries to food security in some countries and sub-national areas and how action on ecosystem restoration can sustain this.

79. To develop a routine global assessment of inland fisheries will require commitment and additional resources to undertake assessments of the indicator fisheries on a routine basis and an agreement to report into a common framework. This would enable FAO to collate a global assessment in a similar manner to that of the FAO marine stock status assessment.

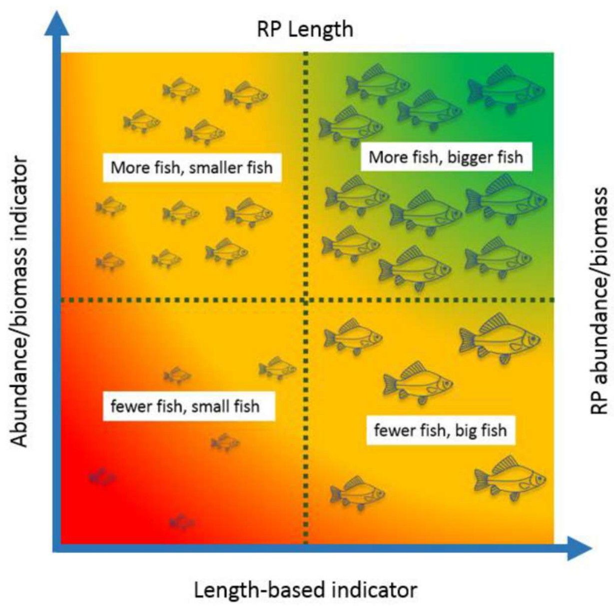
80. The Roundtable considered how a set of indicator basins that provide insight into the state of the fisheries in each region might be identified, and how to prioritize fisheries to be monitored, within that basin. Appropriate tools for monitoring relatively data-poor systems are discussed below.
To aid the understanding of the global threat assessment, the global distribution of inland fish catches by basins was a useful supporting piece of information by the Roundtable.

5. LOCAL ASSESSMENT OF DATA POOR INLAND FISHERIES USING LENGTH-BASED APPROACHES

81. The desirable outcome of biologically sustainable fisheries depends on maintaining spawning stock biomass (SSB) and preventing significant truncation of age structure. Size-selective fishing pressure typically depletes a population and simultaneously curtails the upper end of the size-distribution. In data limited situations, empirical (‘model-free’) indicators can capture trends in both components: abundance indices (e.g., CPUE) and demography (length and age structure). Depending on data-availability, they can provide anything from a robust state assessment down to ‘a rough indication of the state of a fishery’.

82. Community-level indicators are probably the only realistic option where many species are harvested together and their management cannot be separated, e.g., in inherently multi-species tropical fisheries. The "Large Fish Indicator" is the proportion of ‘large’ fish in the assemblage, and thus reflects size-selective fishing, fishing effort and recruitment of small fish/species. Empirical indicators of CPUE and size-structure can fulfil most of these requirements, as they are conceptually simple and are likely to reproduce fishers' understanding that exploited stocks and assemblages become less abundant and larger individuals and species less frequently seen. To be able to "sell" the outcomes of the analysis (and elicit local knowledge), it is important that indicators are presented in a way that is intuitive and visually appealing, and that clearly shows positive or negative trends in state (Shephard *et al*., 2019; Figure 9).

Figure 9: Presenting surveillance indicators for data-limited inland fish stocks: the x-axis is an appropriate length-based indicator and the y-axis is an associated CPUE indicator. Colored regions refer to poor (red), moderate (amber) and good (green) state. The dashed thresholds are potential management reference points (RPs) that may be defined using local knowledge, although a reference direction approach is simpler.



83. Ecological indicators can be used ‘operationally’, having well-understood pressure-state relationships and objective management reference points. Model-free management procedures using empirical indicators have the potential to be effective as the basis for decision-making in data-limited fisheries and may constitute a good starting point for assessing single-species fisheries when more information becomes available and it will be possible to move towards management using simple models. Alternatively, indicators may take a ‘surveillance’ role in tracking ecological state, providing complementary information (including warning signals) that may inform and support science, policy, and management. Users could be co-management groups who need only an approximate impression of state to inform technical management measures or ‘nudges’ in fishing behavior, or ‘barefoot ecologists’ working at the local level in complex small-scale systems.

84. A single-species assessment tool is the length-based spawning potential ratio (LB-SPR) model (Hordyk, Loneragan, and Prince, 2015) SPR is defined as the proportion of un-fished reproductive potential left at any given level of fishing pressure and is commonly used to set target and limit reference points for fisheries. The un-fished length distribution of a fish population can be predicted from the ratio of natural mortality to growth rate (M/K), when von Bertalanffy asymptotic length (L_∞) is known or can be inferred from length data. Inputs of length at maturity (L_m) allow un-fished spawning potential to be estimated from

expected numbers of individuals at that size. The LB-SPR approach uses maximum likelihood methods to find the values of relative fishing mortality (F/M) and selectivity-at-length that minimize the difference between the observed length composition of a fishery catch, and the length distribution predicted by the model, and calculates the resulting SPR. The estimated SPR can then be used as an indicator of the status of the stock for management of the fishery.

5.1 PILOT STUDIES

85. Size-based stock assessments, based on empirical indicators or models such as LB-SPR, are uncommon in inland systems. Previous inland fishery applications have focused mostly on temperate salmonids, but there is a pressing need to evaluate these techniques in data-limited tropical and temperate systems for non-salmonid species.

86. Fürst, Volk and Makeschin (2010) suggested that "Appropriate (ecosystem) management requires:(i) harmonizing and integrating different datasets; (ii) selecting the right indicators; (iii) fitting the right models to the right scale; and (iv) integrating data, indicators and models into systems that allow both a high level of participation and flexibility in application to different questions". This framework was used to inform a set of assessment case-studies. The intention was to provide a hierarchy of approaches that can be applied to a fishery depending on data availability; where the starting point is local knowledge only, moving up to empirical indicators and then to LB-SPR when life history parameter estimates are available. Size-based assessment may be applicable to fisheries that target one or a few single stocks but these approaches are likely to be less valuable in non-selective multi-species fisheries. The case-studies thus focus on ecologically-important target species, or species that form the bulk of the catch in a fishery: (i) four cyprinid species in the Tonlé Sap River (Cambodia); (ii) recreational fisheries in southern Africa; (iii) three species of pimelodid catfish in the Amazon Basin (Peru, Colombia, Brazil); (iv) the sábalo fishery in the lower Paraná River (Argentina); and (v) a Nile tilapia fishery in Lago Bayano (Panama).

87. Each case was evaluated for data quality, and the availability of supporting life history information. An empirical indicator approach or model (LB-SPR) was then selected and applied. Challenges identified in each case were highlighted and discussed.

5.2 RESULTS OF PILOT STUDIES

88. These case studies consider issues including spatial separation of life history stages (Amazon catfishes), strong modality in population size-structure (Paraná sábalo), and fishing gear selectivity. The temporal trends in stock state were interpreted by local experts. Empirical indicators showed strong decline in size-structure and relative abundance for one of four assessed Tonlé Sap fish stocks (Figure 10), while no trend was evident for other tested stocks. The data for recreational fisheries in Southern Africa show how different management objectives may drive the size composition of fish stocks in one or the other direction (Figure 11 A-E).The length-based spawning potential ratio model (LB-SPR) suggested that two of three assessed Amazon catfish stocks (Figure 12) and the sábalo stock in the Paraná River (Figure 13) were below sustainable SPR reference points. The Lago Bayano tilapia stock appeared healthy (Figure 14). The background and the outcome of the pilot study was presented to the Roundtable, and the case studies were discussed individually given that each setting was unique and provided different challenges.

Tonlé Sap Dai fisheries, Cambodia

89. The *dai* fishery is an important large-scale fishery in Cambodia taking approximately 7 percent of Cambodia's total inland fish catch. Overall CPUE is stable, although there has been a decline for some species while for others an increase. In recent years, the peak flood levels have been lower and flows in the dry season have been higher reducing the flood pulse effect. Some species respond immediately to changes in the flood-pulse, while there is a 2-3-year delay for others.

90. In 2001, a process of abolishing the fishing lots around the Great Lake was initiated. In the beginning, this resulted in a small increase in *dai* catches, but shortly after, a decline started, which has continued since then due to the open access. In 2003 and 2004, where the flood levels were very low, the

rice fields in Vietnam were disconnected from the river, which may have impacted the fisheries in the Tonlé Sap due to the migrations.

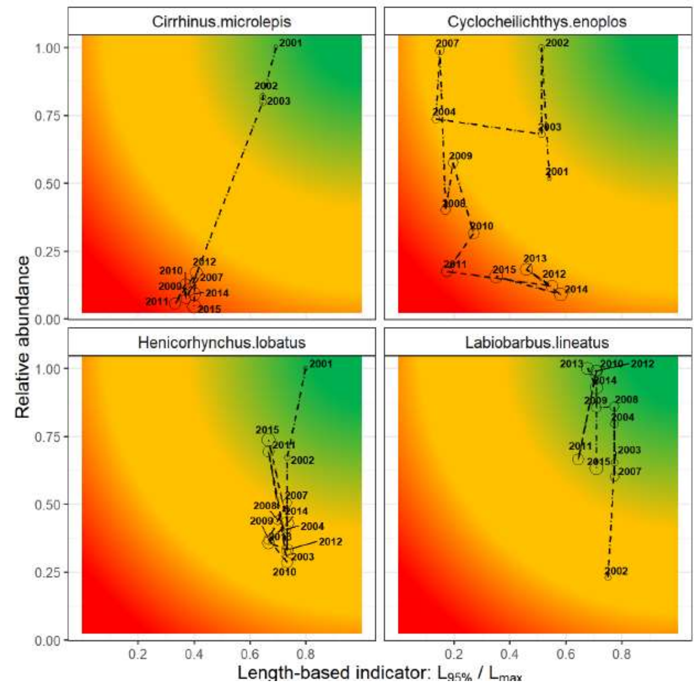


Figure 10: The Dai fishery data supported an empirical indicator approach to assessment, with lack of available life history parameters precluding application of LB-SPR. Time series of relative abundance and a length-based indicator for four fish species measured in random samples from the Tonlé Sap Dai fishery (2001-2015).
Relative abundance is the annual proportion of a species by number in the total catch of the four study species, standardized to the maximum observed value for that species.
The color scale is arbitrary, and simply indicates reference direction from good (green) to poor (red) state.

Using length-based data to assess recreational fisheries in southern Africa

91. Recreational fisheries in southern Africa are poorly understood because of lack of available data on catch and effort. Many recreational anglers in the region participate in angling tournaments during which catches are enumerated and weighed to determine the ultimate winner (see Hargrove *et al*. 2015; Barkhuizen, Weyl and van As, 2017). As a result, catch data from black bass angling tournaments provide the opportunity to derive indices of both, abundance and average weight from fisheries (see Hargrove *et al*., 2014). This is because such data are collected in a standardized format. Tournament anglers fish only for black bass species (largemouth bass *Micropterus salmoides*, smallmouth bass *M. dolomieu* or spotted bass *M. punctulatus*). The rules are consistent between tournaments and include the use of boats equipped with livewells, a 30 cm minimum length limit, dead fish penalties and a 5-fish catch limit (Hargrove *et al*., 2015). Although no individual length data are available, the number and weight of each angler's catch are documented.

92. Here, we illustrate how these tournament data may have considerable potential for the application of size-based approaches to obtain insights into the state of fisheries on various impoundments and the development of individual fisheries over time. In Figure 11 A-E data for competitive angling tournaments held at 25 reservoirs in southern Africa are presented using tournament CPUE (fish/angler.day^{-1}) and mean weight data published in Hargrove *et al*. (2015)[6] to provide a comparative visualization of the performance of each fishery. Relative abundance was expressed as the mean CPUE as a proportion of a possible 5-fish limit, and mean weight was estimated as the mean of the average weight of fish caught by each angler. A proxy for fish quality was derived by weight converting the Gabelhouse (1984) preferred length of largemouth bass to weight (in this case 1 kg) using Schneider (2000). Subsequently, data from annual tournaments were plotted for four reservoirs to illustrate how these data may indicate the state of the fishery.

93. The size plots of tournament catch data illustrate how the four reservoir fisheries have performed over time: Wriggleswade Dam (Fig 11B) is a reservoir with consistent recruitment and large population sizes, which result in consistently high catch rates of small largemouth bass. In Clanwilliam Dam (South Africa's premier smallmouth bass fishery) (Fig. 11 C), strong year classes appear to result in periodic high

abundance (CPUE) of large fish as seen from 2009-2012. Mean size decreased as larger fish (presumably from a good recruitment year) were depleted. Abundance remained high and after a reduction in fish size, this is again increasing in 2017-2018. Vaal Barrage (Figure 11 D) is an example of a reservoir where abundance has been improving since 2009 and in recent years also size is increasing. In contrast, records from Quaggaskloof (Fig. 11 E) indicate a recruitment limited fishery where catch rates (and abundance) have declined. This is driven by recruitment failure considered to be compromised by catfish invasion and declining water levels. The effects are increasing mean size (as fish grow), but a decrease in abundance as fewer or no recruits enter the fishery.

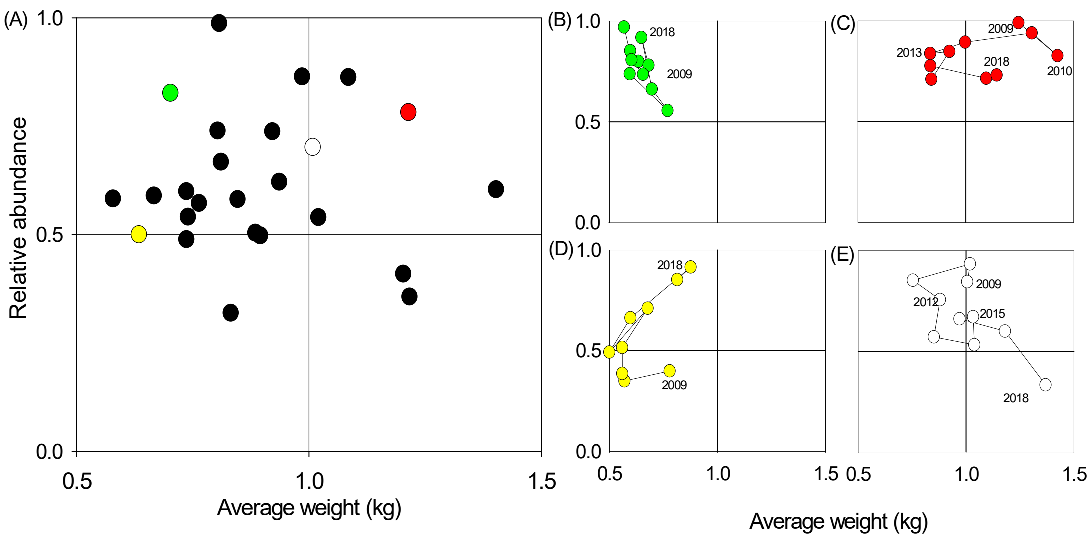


Figure 11: A: Relative abundance and average weight of fish landed in black bass tournaments held across 25 reservoirs located in southern Africa. Green, red, yellow, and white circles refer to four South African reservoirs further explored in B-E where the temporal trend in abundance and average weight of fish caught in the fishery have been plotted. B: Wriggleswade Dam, C: Clanwilliam Dam, D: Vaal Barrage and E: Quaggaskloof Reservoir.

94. This underscores that the management objective can be a strong determinant on the assessment of fishery performance. Recreational fishers like to catch large fish, and an increase in their numbers may be the success criterion for them, even if it means that fish abundance (and therefore likelihood of catching a fish) is lower.

Amazon Goliath catfish fishery

95. The LB-SPR model seemed to show good fit to the annual length data for each of the three tested Goliath catfish species (dourada (*Brachyplatystoma rousseauxii*), piraíba (*B. filamentosum*) and piramutaba (*B. vaillantii*)). The LB-SPR estimates for the three species showed a strong effect of input L_∞ values, and a lesser effect of M/K. Both dourada and piramutaba showed reasonable state for 2001-2004, with a possible subsequent decline for piramutaba. The last species Piraíba showed declining state in the Madeira River, and almost complete absence of larger fish in the Xingu River.

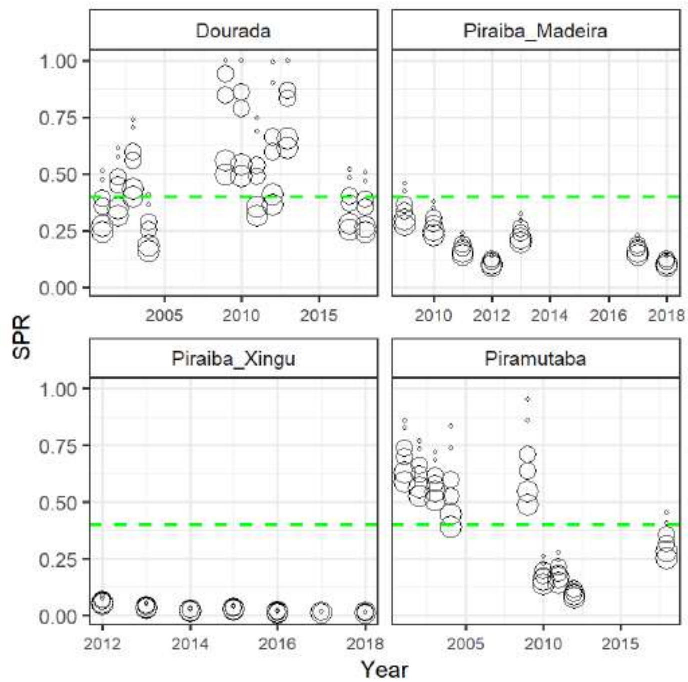
96. The current state differs markedly between the three species. The state of piraíba/filhote is of concern, different tested values of L_∞ and M/K make little difference to the estimated SPR values. This species is targeted below size at maturity and population size-structure is impaired. Piramutaba population state declined during the study period, reflecting high mortality in the trawl fishery in the estuary. Pressure on daurade is increasing, and the state of this stock should be monitored. The case study highlights the need

to consider spatial segregation of life history components of a stock in length-based assessments, possibly by spatially stratifying sampling to collect an overall representative sample of the stock. SPR analysis should be complemented with Local Expert Knowledge to avoid misinterpretation of observed trends. In this study, the length data was collected by researchers or research assistants, and samples were taken directly from the boats at the landing sites. The life history parameters were estimated in a separate study.

97. According to the local experts working in the Amazon, the outcomes of the analysis appear to be reasonable. The same gears are being used for all the species, but it should be noted that there is variation in gears being used among the different sites as the mesh size used increases along the river (in the upstream direction) because the size increase of the fish.

98. The data on the gears is also available but was not included in the analysis. The analysis assumed that most of the fish were caught with drift nets and not set gill nets. This means that there is less of a problem with dome shaped selectivity i.e. all fish above a certain size that encounter the gear, are caught.

Figure 12: Estimates of Spawner Potential Ratio for each of three study catfish species, using different values for the input life history parameters.
Two different datasets were used for piraíba, representing samples from the Madeira and Xingu rivers. The size of the circles refers to L∞, which had the strongest effect on SPR, while M/K ratio has less influence.
The green dashed line provides a good state reference point (SPR = 0.4).



99. The Roundtable queried whether fishers get better prices for larger sized fish. The reason is that if the price per kg is the same there will be a bias towards targeting smaller fish because the fishers will try to maximize catch volume.

100. There might be a problem with the data for the Xingu River, because there is a natural barrier and the migration behavior of the fish has not been studied, and it is unknown how that may affect the size of the fish.

101. If fishing effort in the estuary increases, it will affect recruitment but there are regulations in place to control effort. Two dams were closed in the Madeira in 2012. The construction of the dams had an impact on piramutaba in 2010. However, the length of this species already declined in 2004 and upstream after the river closure due to lack of juvenile sizes migrating from the estuary and not passing the dams.

Sábalo fishery in the lower Paraná (Argentina)

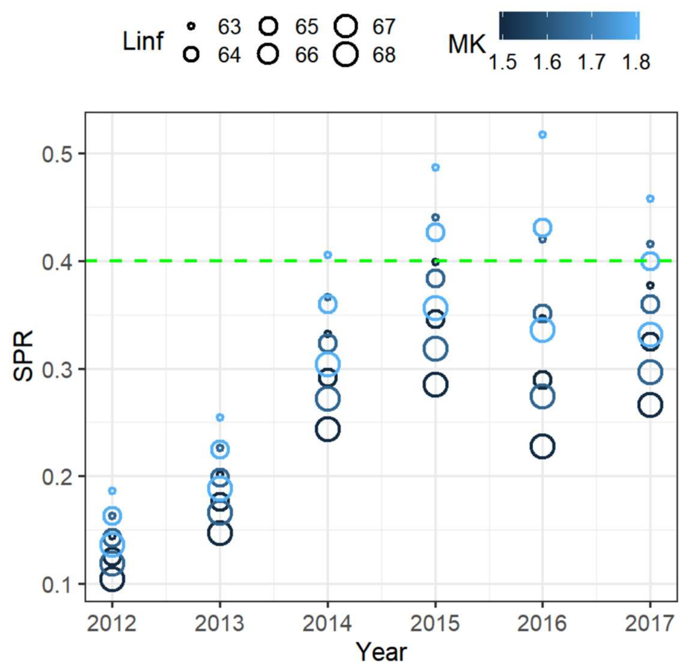
102. The sábalo fishery is the most important in the Paraná Basin in terms of catch volume. The sábalo is a detritivorous species, its maximum size is 60-70 cm and it constitutes about 60 percent of the fish biomass in the basin. The life history parameters vary among different sub-basins.

103. Several fishing gears are used, but the most important in the Paraná (Argentina) are gillnets as hooks do not work. There are certain gear regulations, but they are not the same everywhere. Legal mesh size is generally 8 cm (bar), but in some provinces 6 cm is allowed. This may give problems with selectivity when analyzing data from fisheries. However, for the purpose of this analysis, data from experimental fishing gangs was used.

104. Sábalo stocks had been fished down due to uncontrolled exports in early 2000s, reaching 40 000 tonnes in 2004. In 2006, the fishery became to be regulated but without having a reliable scientific basis on its sustainable level. The LB SPR estimates suggest that the stock has recovered after catch regulations but is still fully exploited with an annual catch of around 15 000 to 20 000 tonnes. Whereas the period 1972 to 1999 was wet and the average flow increased, the period 2000-2010 was dry. Such climatic variability suggests that the sábalo stock would nevertheless be exposed to increased risk if hydrological scenarios were adverse to successful recruitment and juvenile survival in the floodplains during dry years.

Figure 13: Estimates of Spawner Potential Ratio (SPR) for sábalo in the Paraná River, using different values for the input life history parameters L∞ (cm) and M/K (see above).

The green dashed line provides a candidate good state reference point (SPR = 0.4).



Lago Bayano Tilapia fishery (Panama)

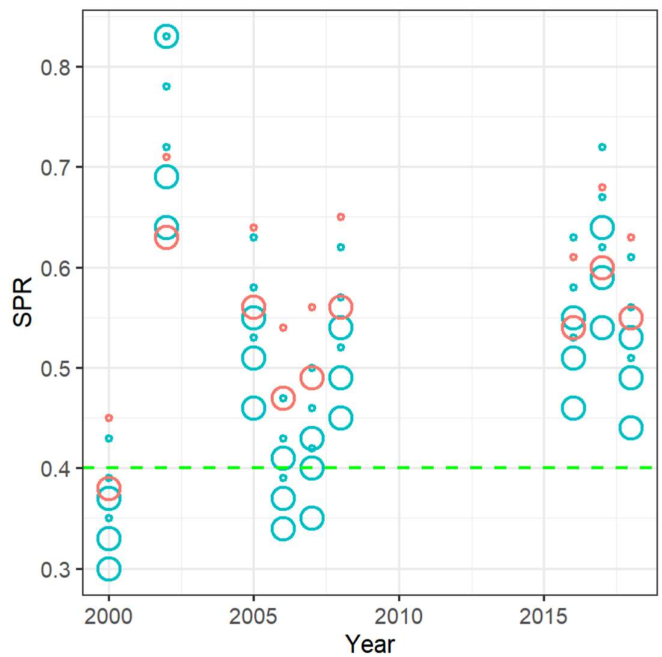
105. The tilapia fishery in Lago Bayano is by far the largest inland fishery in Panama. A fishery management plan was implemented in 2009. The management plan only allows fishing with trammel nets with a minimum mesh size of 5" and fishing is only allowed four days a week.
Low demand for tilapia has led to a decline in the number of fishers exploiting the reservoir. However, despite a significant decline in the number of fishers, CPUE is almost unaffected. This is because of falling demand since middlemen are now buying much less fish from each fisher.

The LB-SPR model seemed to provide good fit to the Lago Bayano tilapia data. Annual SPR estimates suggested that the tilapia stock state has improved since the implementation of a management plan, with SPR values consistently above a conservative sustainability reference point of 0.4.

106. The Roundtable observed that just by seeing the CPUE and the mesh size, it is possible to assess the state of the fishery and a model is not necessary to assess the fishery in this case. The fishery is obviously in a good condition, and the need for management measures reducing the effort was questioned. It was explained that it was because the fishers themselves asked for these.

107. It was also questioned whether reducing the number of fishing days in the week will give the same result as having a closed season for a species which reproduces all the year round such as the tilapia. There is now clear evidence that episodic climate macro-events such as ENSO (El Niño-Southern Oscillation) have a strong impact on spawning and recruitment success of this and other species that spawn seasonal and use floodplains as nurseries. Thus, normal and extraordinary favorable or adverse hydrological pulses play a critical role in defining length structure and cohort strength of sábalo populations.

Figure 14: Estimates of Spawner Potential Ratio (SPR) for tilapia in Lago Bayano, using different values for the input life history parameters L∞ (cm) and M/K (see above).
Blue circles are estimates from the model assuming dome-shaped gear selection, while red circles assume logistic selection.
The green dashed line provides a good state reference point (SPR = 0.4).



108. The Roundtable observed that just by seeing the CPUE and the mesh size, it is possible to assess the state of the fishery and a model is not necessary to assess the fishery in this case. The fishery is obviously in a good condition, and the need for management measures reducing the effort was questioned. It was explained that it was because the fishers themselves asked for these. It was also questioned whether reducing the number of fishing days in the week will give the same result as having a closed season for a species which reproduces all the year round such as the tilapia.

5.3 THE APPLICATION OF LENGTH-BASED APPROACHES IN DATA POOR FISHERIES

109. Based on the four case studies, the Roundtable concluded that data-limited assessment methods may provide guidance for the sustainable management of important target species in inland fisheries. However, the tested methods are probably less applicable in non-selective fisheries where small species are preferred, or in river fisheries with extreme dependence on flood pulses. Important considerations are species life history and spatial distribution, environmental variability, and data collection strategy. Data-limited methods should not be applied as a low risk or technically trivial exercise, and the process, uncertainties and outcomes must be critically confronted. When the limitations of the methods are unknown, it is important that the sample is sufficiently large to allow correct and unbiased interpretation of the analysis.

5.3.1 ISSUES AND SOLUTIONS IN THE APPLICATION OF LENGTH-BASED ASSESSMENT APPROACHES

Length-based indicators

110. The Roundtable reviewed a range of issues that relate to the potential for application of LB assessment approaches. The first (empirical and local knowledge approach) does not provide objective management reference points (RP), but has potential as a flexible first-order assessment tool. The dynamics of floodplain river fisheries can vary strongly with hydrological regime as a consequence of natural fluctuations or anthropogenic activities such as damming. Consequences such as episodic recruitment of target species may be best understood in discussion with the fishing community or through experimental fishing. Simple empirical indicators and indicator plots provide an excellent framework for this convergence of minimal numerical data and expert insight (Shephard *et al*., 2019). The Roundtable was generally comfortable with this framework and made some useful suggestions for further development and 'holistic' inclusion of additional data and/or expert knowledge (see below).

Length-based Spawning Potential Ratio model

111. The LB-SPR model has a strong theoretical foundation and can provide RP, meaning that it may be the preferable tool in systems where data support and life history information are available. In many cases this information need can be resolved or would require some sort of mitigating action. In other cases, the LB-SPR model assumptions or input requirements constitute limitations on the approach and this increases uncertainty of the result. These are summarized in Table 9.

Assumptions about gear selectivity

112. The original LB-SPR model assumption is that study gears have a logistic (trawl-type) selection profile, but this pattern is relatively uncommon in inland systems. The model has recently been extended to account for dome-shaped (gillnet or hook and line) selection, allowing application across most of the gear types commonly used in inland fisheries (Hommick *et al*., *in pres*s). It is not yet possible for the model to estimate dome-shaped selection internally, and so input selectivity parameters from an experimental evaluation of each gear are required. Such information, with few exceptions such as the sábalo fishery in the Parana River, is usually not available for inland fisheries. This requirement may be particularly difficult to meet in complex, multi-gear fisheries:

- Selection parameters may be difficult to estimate for multi-gear fisheries or cases where the catch is pooled across several (possibly unknown) gear types.
    - It is very important to know the characteristics (hanging ratio, material, mesh size, etc.) of the gears used in the fishery in order to address selectivity issues and make the results comparable among fisheries.
        - It is highly recommended that samples are taken from individual fisherman, not traders
    - Can the model accommodate changes in selectivity occurring over time?
        - Yes, if we know how the selectivity changes and can estimate shifts in selection parameters.
    - Ideally, a selectivity experiment is undertaken, but this has to be done over the course of the year or the fishing season and this is already approximating to a data-rich fishery assessment or alternatively by using gangs of experimental nets, which, if properly designed will allow for the capture of fish with a wide range of sizes and tracing the cohorts over time.
    - Selectivity is not constant in a river system.

113. Some of the above limitations are difficult to overcome in diffuse river fisheries where fish are landed at ports and transported by middlemen making it impossible to make the connection between the fish and the gear that captured them.

Issues with estimating natural mortality M

114. The LB-SPR method assumes that fishing and natural mortality are the only drivers of changes in size-structure in the vulnerable (fished) component of a target population, i.e., assumes a steady state. This is typically the case in marine systems, but in inland fisheries there are often other very significant anthropogenic pressures such as large dams or loss of floodplain connectivity.

115. These factors could influence recruitment and growth, and thus impose additional shifts in size-structure on top of fishery impacts. There are also more theoretical questions around estimates of M and von Bertalanffy K:

- Natural mortality changes over time with age of the fish, but in data poor situations it is necessary to make some assumptions. M is also driven by environmental parameters that can exhibit a large variability especially in large river floodplain systems. L, K and L_∞ are variables, not parameters. There are papers discussing these issues in depth and model inputs can use a set of likely values, supporting a simple sensitivity analysis.
- The model requires an input estimate of M/K, which is a life history trait that is strongly predictable from species taxonomy or species family and relatively stable within a certain range.
- The model is sensitive to the input estimate of L_∞. Caution should be taken in extrapolating values from other systems as L_∞ often strongly differs among basins with very different characteristics. If extrapolated, it should be considered that L_∞ predicted from L_{max} could be biased when fisheries have been subject to high fishing pressure.

Sensitivity of the LB-SPR method

- The underlying input parameters: M, K, L_∞ are all variables, although the actual input is M/K, which is a much more stable life history value predictable from taxonomy.
- In each case, it is necessary to carefully evaluate whether the underlying assumptions are realistic:
  - What sort of ranges are there within a system?
  - How sensitive is the model to these variables?
- Hordyk *et al*. (2015) provide a robust sensitivity analysis, evaluating how the LB-SPR model is likely to respond to errors in input parameters.

Reference points for LB-SPR in inland fisheries

116. LB-SPR supports application of absolute SPR RPs, but can also be used for reference direction assessment like the empirical plot methods considered elsewhere in this report:

- Should the reference point be 0.4?
- Marine LB approaches use 0.25-0.3 so this is conservative.

117. When defining a RP, species life strategy may become a critical issue as periodic species that usually represent some of the main target species in large rivers, probably exhibit higher recovery capacity from exploitation or natural mortality. There is not enough knowledge available to select appropriate RPs in inland fisheries since recruitment and cohort strength are probably never constant, and RP values may vary according to hydrological conditions. The RP of 0.4 used in the plots is therefore very preliminary and conservative and it should be discussed whether it is appropriate, and how it might change to anticipate hydrological variability.

Effects of environmental variables

118. The effects of other anthropogenic pressures than fishing on fish population size structure are important research questions in themselves. For example, what is the relationship between environmental parameters including the flow regime and annual recruitment strength? Such questions are probably accessible via studies that use size-based mathematical models that can track size-structure through pressure-state scenarios, such as physical river barriers that restrict access to spawning grounds and hence impair recruitment:

- Dams and flow regulation affect recruitment;
- River-floodplain connectivity can influence recruitment and growth performance;
- Hydrological attributes such residence time, amplitude, intensity, etc. could have effect on species' natural mortality; and
- Flow is important for catchability and therefore could promote a segregation of fish length in the catch.

119. There have been various attempts to adapt marine models to inland fisheries. The models currently used in marine fisheries were initially developed in the 1950s, and newer models are often variations over the same theme. Some of these complex models may work for stable fisheries (i.e. large lakes). The advantage of the LB-SPR model is that it does not attempt intricate parameterizations of a population to closely track state. Instead, the model makes simple assumptions about what good state probably comprises, compares the actual situation to this reference point, and reports on the difference. The small scale and flexibility of inland fisheries mean that LEK will be incredibly informative in interpreting assessment. Episodic large recruitment seems to be common in species with periodic life strategies, shifting the fisheries selection toward smaller fish. This in turn decreases mean length in the catch which could be erroneously interpreted as overfishing, i.e., loss of large individuals.

Table 9: Summary of potential issues and solutions for length-based assessment (indicators or LB-SPR)

Issue	Problem	Limits to application	Possible solution
Small sample size	LB-SPR model fit. If there is a small sampling size, but this includes a few very large fish, it will have a strong effect on the result and skew the indicator.	Need at least 60-100 individuals	Additional sampling or select a few abundant species for assessment.
Spatial issues	Some target fish species may have strong spatial segregation of life history stages. Differently sized fish migrate at different times and large fish generally migrate first.	Length samples may not be representative of underlying population size-distribution.	Spatial stratification of the sample.
	In very long river systems, the huge range of some species will be an issue (size varies along the river length, the gear used may also vary).	Problems may appear when stocks are transboundary and therefore difficult to sample in a standardized way	It is necessary to analyse the catch separately for each site and year separately.
	In some floodplains, fish can constitute meta populations that can become isolated in the floodplain for several years before re-joining the fishery as a water body is reconnected.	Length samples may be different to the population that was not disconnected.	The meta-population is determined by the flooding area; this needs to be accounted for in sampling.
Selectivity issues	Many inland fishery gears (gillnets, hooks and small traps) show dome-shaped selection	Dome-shaped selection is not incorporated in the current LB-SPR.	A modified LB-SPR method has been developed (Hommick *et al.*, in Press). Selection parameters are derived from a selection experiment and provided to the modified model.

Gear mixture	Each gear has different selectivity. Gear use may vary between fishers, sites and seasons.	May cause a problem where catches coming from several different gears are pooled together.	Emphasizes the importance of combining local knowledge with the LB data collected. Avoid combining samples from different gears.
Multi-species and multi-gear fisheries	A species may be captured by more than one gear and catches from these mixed gears may not correspond to the selectivity of one gear.	The modified dome-shaped LB-SPR requires a single set of selection parameters corresponding to the sampling gear.	Length samples should come from only a single gear, ideally the one responsible for most fishing pressure.
Bimodal distributions	Freshwater fish species may often show strongly modal size-distributions due to large inter-annual fluctuations in recruitment related to flood pulses intensity	Potential poor model fit using the LB-SPR model. May not be a serious issue Hordyk *et al.* (2015).	Use an assessment model with an annual recruitment time step that can capture strong peaks in recruitment, e.g., Fitzgerald *et al.* (2019).
Phenotypic plasticity (limits use of data from other studies)	Some species, particularly tilapia, can show strong system-specific differences in life history parameters, e.g., maturation schedule.	The LB-SPR method requires reasonably accurate estimates of life history parameters, and for many species, these values can be borrowed from other systems. This is more difficult for the highly plastic tilapia.	Where possible, assess life history parameters from the study system instead of applying from other systems when strong ecological differences exist.
Climatic effects	Monsoonal fisheries are often highly seasonal as they target fish migrations driven by flood pulses.	The fishery may target different size or life history components in different seasons. Samples from these sub-components may not be representative of the whole underlying population.	Stratify sampling in space and time, e.g., river sections and important season, e.g., dry vs. monsoon season.
	Macro climatic events such as ENSO may have a paramount influence on stocks migration and recruitment.	LB-SPR could be sensitive if length structure is affected by episodic recruitments	Consider life history strategies of species to account for unexpected length structure patterns. Always analyze data from different years separately.
Recruitment	Particularly in multi-species floodplain fisheries there is a surge in annual-recruiting fish.	LB-SPR cannot be used for these fisheries that target only juvenile fishes as they return to the main river channel.	The method may still be applicable to larger, longer-lived species also caught in these fisheries.
	Episodic recruitments	LB-SPR assumes constant recruitment, if there is a large recruitment (due to environmentally favorable conditions) there will be relatively less large fish.	This is only a problem for the large fish indicator. The LB-SPR will still be valid.
Differences between sexes	Female fish often grow larger than males and are therefore larger before reaching sexual maturity.		Not a problem, unless there are strong differences in spatial distribution by sex or life history stage.

5.3.2 CONCLUSIONS – LENGTH-BASED SPAWNING POTENTIAL RATIO-LENGTH-BASED ASSESSMENT

The data requirements for LB-SPR mean that it is still not a truly data-poor approach

120. The Roundtable saw that the LB-SPR case studies above are relatively large-scale and data-rich examples. Many important inland fisheries are smaller and have few data and much more scarce biological understanding. The implication is that even though LB-SPR uses only population length data, and does not require effort data, it is still a relatively data-rich approach. This is because it still requires reasonably good understanding of the selectivity of the gear used and good estimates for some input life history parameters. Also, LB-SPR would provide a general basis for assessing fish stocks or populations status along transboundary basins, where resources management policies often differ. The implication is that the LB-SPR approach in some situations may provide misleading information or no easier than a standard assessment approach that incorporates fishing effort. The Roundtable agreed that it would be helpful to set criteria where the LB-SPR approach can be used effectively.

Advantages

121. The LB-SPR approach requires only a representative sample of catch size structure and reasonable estimates or knowledge of life history parameters. The case studies above show that the model can provide consistent inter-annual evaluations of stock state that concur well with local scientific expert judgement. This outcome suggests that successful applications of LB-SPR in small-scale marine fisheries can be extended robustly to certain inland fishery cases. While the underlying mathematics of the model are somewhat complex, applications elsewhere have shown that fishers can quickly understand the broader concepts of size-based assessment and participate in sampling activities and expert interpretation of results.

Specific limitations

122. The Roundtable concluded that LB-SPR is good for retrospective (i.e., reference direction) analysis, but requires caution if using it for monitoring current state:

- LB-SPR can show changes in the status of a stock. However, it does not reveal the cause (e.g. overfishing or a dam);
- This approach is best applied when the fisheries target only a few species;
- The method cannot be usefully applied in stocks that are based on short-lived, fast-growing species (e.g., small pelagic species or annual recruiting floodplain species) or where there are differences sexing the life history parameters between the sexes;
- When multiple gears (with possible differing selectivity) are used in a fishery, then sample size structures should be analyzed separately;
- Reference points could vary among basins or waterbodies due to differences in biological parameters (K, $L\infty$, L_{max});
- Episodic high recruitments could promote bimodal length structure that confounds the results when this feature is not detected by traditional sampling from commercial fisheries; and
- Most of the gears used in inland fisheries (hooks, gillnets) have a dome-shaped selectivity pattern instead of logistic that come from trawls, rarely used in lakes and rivers.

123. The Roundtable further noted that in situations where the uncertainty involved with data collection and gear selectivity, and noise from possible confounding environmental variables are at such a level that excessive uncertainty is introduced, caution should be applied when interpreting the results. However, if the model or the reference point is too precautionary, then the advice that is obtained will be too conservative and will not be particularly useful for management. The LB approach may thus be less preferable to alternatives such as mixed method approach as described below.

Ideal situation for application of the LB-SPR model

124. The LB-SPR assessment method requires several assumptions to be fulfilled or carefully accounted for. The model will work best with:

- Single stock fisheries or fisheries targeting a small number of important stocks;
- Monitoring should focus on a small number of common gears. A reference direction application could be used by monitoring SPR from this selected set of gears;
- Fishing effort should consistently target a similar size component of the population;
- Recruitment, asymptotic growth and natural mortality remain constant along time; and
- Relatively stable environment.

125. This helps ensure that shifts in catch size-structure reflect underlying demographic change, rather than changing size-preference in the fishery. Strong, environmentally driven shifts in recruitment success (recruits per spawner) will change SPR, and so major hydrological events (including dam building) should be considered.

5.3.3 CONCLUSIONS – OTHER LENGTH-BASED ASSESSMENT APPROACHES

126. The Roundtable also discussed alternative approaches for situations when length-based models such as LB-SPR cannot be used in data-poor fisheries. It was concluded that the combination of empirical indicators and local knowledge will be the only effective/practical approach. This framework makes sense for reference direction evaluation, in cases where the fisheries status may respond to anthropogenic pressures other than fishing when the changes are well perceived by fishers. The appropriate indicators can be selected for a given fishery depending on various considerations, e.g., stock level/community indicators, catch, effort, size, traits-based, length structure, etc. and trends in the fisheries.

Importance of local ecological knowledge to inform an assessment

127. The case studies above show how local expert knowledge can be used to interpret temporal shifts in fish population state (size structure). The weight of local knowledge grows progressively in situations where data availability declines. It should be possible to provide a protocol for situations where an initial fishery evaluation must be conducted and there is a lack of appropriate information (Table 10).

Table 10: Types of fisheries information to obtain through local knowledge

Types of information	Desk study	Landing sites	Fish markets
Background information on the species and their maximum sizes at basin scale.	Obtain professional opinion from local researchers Review literature Consult Fishbase	Gather local knowledge from fishers	Survey main local markets
Size composition of species in the catches	Define indicator species that are important to assess the fisheries (L_{50}, L_c, $L_{95\%}$, L_{opt})	Identify target species and measure the size ranges of fish species in catches Verify the presence of: a) Predators and large long-lived species c) Migratory species d) Indicator species	Take photographs Survey sold species at the market Look at the size of the fish in the markets
Trends in the fisheries	Review literature	Assess the composition of catch (proportion of small individuals and annual recruits, trophic guild). Talk to fishers and middlemen to get their impression of trends in the fishery (where possible validate by cross	Talk to traders about changes in their fish supply

Types of information	Desk study	Landing sites	Fish markets
		checking with other information).	
Temporal fisheries patterns	Review literature	Gather local knowledge from fishers and middlemen about fishing seasonality Consider the recreational fisheries for complementary information	Survey main local markets
Spatial fisheries patterns	Review literature to infer which species are migratory, present meta-population patterns, are ubiquitous, etc.	Gather local knowledge from fishers and middlemen about target species spatial catch	Survey main regional markets

5.3.4 RECOMMENDATIONS ON COMBINING EMPIRICAL LENGTH-BASED ASSESSMENT WITH LOCAL KNOWLEDGE

127. The Roundtable made some recommendations for follow up on this assessment method

- Extend and standardize the current indicator/local knowledge framework;
- Develop a decision tree to guide decisions on which approach to use and which information will be most powerful in a given scenario; and
- Develop/collate some guidance on using local ecological knowledge for fishery assessment (draw from existing FAO work, PARFish etc.).

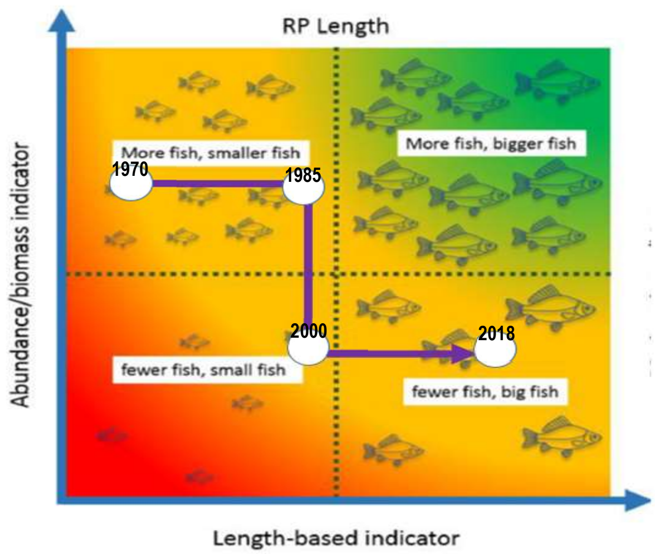
128. The Roundtable elaborated a concept for a 'holistic' standard assessment analysis. The combination of simple empirical indicators and local knowledge was appealing to the Roundtable participants as an accessible framework for assessing very data-poor inland fisheries. The Roundtable discussed ways to present assessment information that would assist in providing a simplified visual summary of the major trends in a fishery and the drivers contributing to its current status. It was emphasized that LB information alone cannot disentangle the various pressures responsible for the state of a fishery, including the influence of the environment in highly variable systems. Complementary information from local knowledge and context is therefore required to make sense of LB plots, and to inform management decisions. A model for such a three-step approach is provided in Figure 15 and 16 and Box 1.

Figure 15: A summary analysis of the trend in the fishery, what is most likely driving it and the degree of certainty based on literature and expert knowledge.

Box 1: Assessment of the fisheries based on local fisher knowledge and fish market surveys

- Changes in the fishery; variability
- Identify indicator species that are important in the fisheries
- Look at the size ranges of fish species in catches
- Presence/state of:
  - ✓ Predators and larger, long-lived species
  - ✓ Migratory species
  - ✓ Indicator species
- Fishery timeline
- Recognize temporal and spatial fisheries variability

Figure 16: Length-based assessment using data from measurements



129. The assessment should be accompanied by simple guidelines on the interpretation of the data and would be useful for:

- Effectively summarize assessment information and make it transparent and understandable for stakeholders (fishers, managers, traders, etc.);
- Allow an effective communication with fishers and policy makers about fisheries trend and how they are moving on a temporal basis;
- Support the adoption of management measures;
- Allow testing the possible effectiveness of past applied management measures; and
- Allow detection of the need to allocate resources to research to validate the observed trends.

130. Experimental fishing using standardized gears can also be a valuable tool to acquire a better picture of fish sizes that commercial fisheries usually cannot provide and is useful to detect fish size and abundance trends.

6. OVERALL CONCLUSIONS

131. The Second Roundtable reviewed progress of work that had been initiated as a response to the recommendations of the *"Advisory Roundtable on the Assessment of Inland Fisheries*", that was

convened in partnership with United States Geological Service (USGS) and Michigan State University (MSU) in FAO Rome, 8-10 May 2018 and covered two main themes.

6.1 REVIEW OF A THREAT ASSESSMENT MAPPING MODEL

Potential

132. It was concluded that the value of mapping threats is that this enables a downscaled evaluation of threats to inland fishery food production and biodiversity at the basin and sub-basin level, as well as prioritizing needs for ecosystem restoration and improved conservation.

133. It was agreed that the model framework developed by this initiative offers much opportunity and made recommendations for its further development.

134. A set of indicator basins provide insight into the state of the fisheries in each region that might be identified and provide clues on how to prioritize fisheries to be monitored, within that basin.

Limitations

135. Threat assessment might not reveal effects that are transferred between sub-basins, particularly upper and lower reaches of the same river basin. The entire basin from source to sea should be included in the analysis because each part of the basin may support different fisheries and be subject to different threats:

- The model appeared to work best with flowing water/river basins;
- Cities, industrial effluents, irrigation channels and other land uses within basins can exert specific and more localized threats; and
- It was noted that the model was built on a base created for the USA and it might thus be more responsive to North American basins and inland fisheries in temperate latitudes, than to fisheries in tropical/subtropical regions.

136. There are limitations of using the influence of the surrounding basin threats to the fishery of a large water bodies, which will respond only slowly to the overall conditions in their basins due to their buffering capacity and internal processes.

137. The use of mixed data from different years does not provide a single baseline year, but a composite picture over a period of years. The Roundtable acknowledged that the rate of change of many of the variables means that this is probably not a major constraint with the current application.

138. The inability to find a common reference point for all basins would be a major constraint. It is also unclear how the model would be able to handle uncertainty.

139. The model assumes that low GDP and high population pressure will tend to drive fishing effort. However, where there is strong cultural resistance to eating fish and in countries with high apparent GDP but with many poor rural fishing households this may not be true.

Suggested improvements and adjustments

140. It was recommended that in order to analyze large complex basins, it will be necessary to correlate the analysis with other sources of information, including expert knowledge:

- Local expert knowledge will be required to produce validations at the same spatial scale as that produced by the model;
- It was emphasized that it will always be a management decision what the objectives of fisheries management are, and thus how values are assigned to the fisheries;

- On the other hand, some elements of governance principles could be included in the accompanying expert validation of the model results; and
- Appropriate tools for monitoring relatively data-poor systems are required.

141. It was considered whether the assessment might need a system for differential weighting according to either the purpose of the fishery (food production, conservation of biodiversity, or recreational fishing), or the environment (arctic, temperate, tropical etc.) within which it operates.

142. Overall, the assessment of threat intensity seemed to be weighted towards a northern hemisphere perspective on threats such as connectivity. While in the case of Africa, these threats were considered relatively less important as the fisheries were largely based around large lakes and other water bodies, and therefore less driven by migratory fish species.

- It was considered important to assess if weightings could capture context dependency.
- It was recommended that due to the issues of buffering capacity and internal processes in large water bodies, a dedicated threat assessment for those water bodies may be necessary. The Roundtable considered the need to incorporate market and economic drivers in the model.
- In all cases, agreement existed that the model should be peer reviewed to confer scientific credibility.

6.2 APPLICATION OF LENGTH-BASED ASSESSMENT METHODS

143. The Roundtable reviewed a range of issues that relate to the potential for application of LB assessment approaches. The Roundtable was generally comfortable with this framework and made some useful suggestions for further development.

Potential

144. It was concluded that LB-SPR is good for retrospective (i.e., reference direction) analysis, but requires caution if using it for monitoring current state.

145. Several advantages were observed such as by recording the CPUE and the mesh size; it is possible to obtain a big picture of the state of the fishery and a model is not necessary to assess the fishery in this case.

Limitations

146. It was noted that where the data collection, gear selectivity, possible confounding environmental variables are at a level such that excessive uncertainty is introduced, it will require precaution in the interpretation of the results.

147. The data requirements for applying the LB-SPR are too demanding for most inland fisheries in developing countries. These fisheries are typically small, have little or no data and limited biological understanding.

148. LB assessment methods require several assumptions to be fulfilled or carefully accounted for and may, in some situations, provide misleading information and be no easier than a standard assessment approach that incorporates fishing effort.

149. In a dynamic and complex basin such as the Mekong, even 10 to 15 years data would not necessarily be enough to provide a reliable analysis. In Africa, in turn, 20 years of data would be needed to cover a complete cycle.

150. It was concluded that for small short-lived species it is questionable whether a length-based assessment makes any sense because fluctuations in the size of these species may be due to differences in

growth and not caused by fishing. The *dai* fishery in the Tonlé Sap/Mekong may therefore not necessarily be a good indicator for the status of the fishery.

151. The Roundtable commented that for small short-lived species it is questionable whether a length-based assessment makes any sense. Fluctuations in these species may be due to differences in growth and not caused by fishing. Further investigation of the application is warranted.

152. Market demands may also influence assessments if landed fish sizes are not related to price and fishers therefore try to maximize catch volume by targeting on small and more abundant species.

153. Caution is required when selecting and considering biological parameters for non-equilibrium stocks that tend to dominate fisheries in most large river floodplain systems, where recruitment and natural mortality may vary among years according to hydrological and related connectivity conditions.

Suggested improvements

154. It was agreed that it would be helpful to set criteria where the LB-SPR approach can be used effectively, considering a suite of different fishing and environmental scenarios. \

155. It was also discussed what to do when length-based models such as LB-SPR cannot be used, and it was found that with most data-poor fisheries, the intuitive combination of empirical indicators and expert knowledge will be the only effective/practical approach.

156. The Roundtable discussed ways to present assessment information that would assist in providing a simplified visual summary of the major trends in a fishery and the drivers contributing to its current status.

6.3 FOLLOW-UP TO THE ROUNDTABLE MEETING

157. The final session of the Roundtable identified and discussed several follow-up actions to build on the progress that had been made with the work presented at the Roundtable. Substantive deliverables and actions were as follows:

i. A workshop report summarizing the review of the methods presented at the Roundtable and summary of discussions and conclusions (FAO);
ii. A Fisheries Circular, which provides a detailed background to length-based assessments, and a detailed account of the case studies will be developed (FAO);
iii. A journal article, which summarizes the Fisheries Circular will also be developed (Case-stud
iv. y authors);
v. A decision on how to proceed with the threat-based assessment approach and how to present the results for an analysis of the major inland fishery basins of the world (Univ. of Florida/USGS with input from Roundtable members); and
vi. Finalization of a review of major inland fisheries basins (Hull International Fishery Institute/FAO)

Annex I: Roundtable agenda

Time	Activity	Notes
Day 1: Monday 25 November		
08.30-09.00	Arrive at the Philippine room	Registration etc.
09.00-09.15	Open, introductions	Round the table introductions
09.15-09.30	FAO presentation - orientation to the objectives of the Roundtable Simon Funge-Smith	Some background Why FAO needs to do this What we have been trying to develop What we are looking to get out of the Roundtable Refer to previous report, add in the SOFIA/C942
09.30-10.00	Orientation presentation on the threat assessment method *Gretchen Stokes*	Recorded (link to be provided)
10.00-11.00	Q&A on the methodology and comments on the strengths and limitations	Hydro units, data summaries, weights (global vs. basin), incorporating harvest, validation
11.00-11.15	Break	
11.15-11.45	Intro to group activity on basin weighting	Exercise overview and framing
11.45-12.30	Break out group activity - basin weighting exercise	Groups list and weight threats across major basins by expert opinion
12.30-13.30	Lunch	
13.30-14.15	Continue group activity - basin weighting exercise	Cont.
14.15-15.00	Compare with basin threat maps	Reality check/general impression of current basin maps; What data might be missing?
15.00-15.15	Break	
15.15-16.30	Break out groups - Report back to plenary	Report back - findings, reservations, improvements Discuss what is missing, incorrect, etc.
16.30-17.00	Day 1 wrap-up	
Day 2: Tuesday 26 November		
09.00-10.00	Preparation/comment on the text and report section for SOFIA Finalizing this assessment	What needs to be accomplished to get this version finalized?
10.00-10.30	Opportunities	Highlight basin-level example, user interface, auto-updates
10.30-10.45	Break	
10.45-11.45	Sustainability, replicability of future assessments	How to move beyond a snapshot approach for the assessment? Maintaining continuity, transferability and momentum as a group?
11.45-12.30	Action items: Where next with the approach?	Leaving the Roundtable with an agreed path forward (paper, basin report, etc.)
12.30-13.30	Lunch	
13.30-14.00	Overview of the data poor length-based method Sam Shephard	Recorded (link to be provided)
14:00-14.30	Discussion, general Q&A	Recorded (link to be provided) Felix General applications, limitations Tables 4 & 8 from Length based assessment report as handout
14.30-15.30	Goliath catfish-fisheries in the Amazon *Brazilian team* (overview 5 min)	Can the method be applied? Do the results make sense in this context? Are there issues that would limit/prevent its use?

Time	Activity	Notes
	Sam Shephard (analysis and results 10 min) Plenary discussion (45 minutes)	Where else might this be applied?
15.30-15.45	Break	
15.45-16.45	Tilapia-fisheries in Lago Bayano *Alexis Peña* (overview 5 min) *Sam Shephard* (analysis and results 10 min) Plenary discussion (45 minutes)	Can the method be applied? Do the results make sense in this context? Are there issues that would limit/prevent its use? Where else might this be applied?
16.45-17.15	Length Based Approaches in a Catch Assessment framework. *Rishi Sharma*	Adding in the catch and effort to the tilapia & catfish case studies Includes Q&A
Day 3: Wednesday 27 November		
09:00-10:00	Dai-fisheries in Tonlé Sap *Ngor Peng Bun* (overview 5 min) *Sam Shephard* (analysis and results 10 min) Plenary discussion (45 minutes)	Can the method be applied? Do the results make sense in this context? Are there issues that would limit/prevent its use? Where else might this be applied?
10.00-11.00	Sábalo-fisheries in the Paraná *Claudio Baigún* (overview 5 min) *Sam Shephard* (analysis and results 10 min) Plenary discussion (45 minutes)	Can the method be applied? Do the results make sense in this context? Are there issues that would limit/prevent its use? Where else might this be applied?
11.00-11.15	Break	
11:15-12:30	Summarizing the advice and completing Table 4 and Table 8.	Provisos, warnings on confidence or misleading results
12.30-13.30	Lunch	
13.30-14.30	What is the potential to apply these methods globally? Making the method more accessible - how to guide and promote?	Do we have any alternative methods? Developing a "How to"?
14:30-15:30	Wrap up, conclusions	Identify next steps. Circular, Paper in Fish and Fisheries LB methods Reporting threat assessment to COFI
15.30-15.45	Break	
15.45-17.00	Wrap up, conclusions cont.	

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The Second Advisory Roundtable on the Assessment of Inland Fisheries covered two aspects of the assessment of inland fisheries:

1) A threat mapping framework intended to support the management of aquatic systems and the continued delivery of ecosystem services. The status map produced provides a visual (and quantifiable) relative indication of the levels of anthropogenic and natural environmental pressures to inland fisheries at the basin or sub-basin level. Five major threats to inland fisheries (and their 21 sub-threat categories) were scored according to global studies and modelling. Connectivity and land use were the highest weighted variables, with close agreement between literature and expert opinion. Literature and expert opinion disagreed on the relative importance of water abstraction and pollution. The Roundtable noted that the assessment appeared to work better with flowing water/river basins rather than large water bodies. It was also noted that specific and more localized pressures from cities or irrigation and other land uses within basins may have local effects rather than basin-scale impacts. The Roundtable concluded that local expert knowledge will still be required to validate model findings and ground-truth results in the local context. The Roundtable also concluded that the value of mapping pressures is that it enables an objective, downscaled evaluation of potential threats to inland fishery food production and biodiversity at the basin and sub-basin level. It also enables the prioritization of needs for ecosystem restoration and improved conservation.

2) A review of the potential of using length-based (LB) assessment methods as a tool to support management advice in data-poor inland fisheries. Simple indicators such as abundance and size distribution of the fish caught in combination with local knowledge can enable better understanding of underlying causes of historical trends in a fishery and an indication of the current status of a fish stock. This can be further used to inform planning using the Ecosystem Approach to Fisheries management (EAFm). Where information about the life cycles of the fish (i.e. size at maturity) is available, the Length-Based Spawning Potential (LB-SPR) model can be applied, otherwise, simpler empirical LB models must be used. The two approaches have been applied to data from five inland fisheries: the Tonlé Sap dai fishery in Cambodia; the tilapia fishery in Lago Bayano, Panama; the sábalo fishery in Paraná, Argentina; the goliath catfish fishery in the Amazon Basin and four recreational fisheries in South Africa. The case studies showed that the LB-SPR model can provide consistent inter-annual evaluations of stock state that concur well with local scientific expert judgement, and the model can therefore be used in certain inland fisheries. However, LB assessment methods require a number of assumptions to be fulfilled, and may, in some situations, provide misleading information. They may also be no easier than a standard assessment approach that incorporates fishing effort. The Roundtable suggested some criteria where the LB-SPR approach can be used effectively and agreed that these should be more comprehensively elaborated. With the most data-poor fisheries, the intuitive combination of empirical indicators and expert narrative will be the only effective/practical approach.

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