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Review

Identifying Indicators to Evaluate Community-Managed Freshwater Protected Areas in the Lower Mekong Basin: A Review of Marine and Freshwater Examples

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Abstract: Protected areas are frequently established as a management tool to conserve terrestrial and aquatic habitats and species. Monitoring and evaluation are a necessary part of adaptive management to determine whether such protected areas are effectively meeting their objectives. While numerous initiatives have developed methods to evaluate terrestrial and marine protected areas (MPAs), similar efforts and resources are lacking for freshwater protected areas (FPAs), which have become widespread as a community-based fisheries management approach in the Lower Mekong Basin (LMB). This review summarizes published literature on the evaluation of marine and freshwater protected areas to provide guidance on the evaluation of community-managed FPAs in the LMB. Specifically, the review examines several indicators related to common objectives of aquatic protected areas and provides considerations for measuring these indicators in the context of community-managed freshwater protected areas in the LMB. Key conclusions include that first, FPAs should be established with clearly defined objectives, and these objectives should inform the selection of indicators for evaluation. Second, indicators identified for MPAs are highly relevant to FPAs, although methods may require adaptation to a freshwater environment. Finally, socioeconomic and governance indicators are overlooked in both MPA and FPA evaluations compared to biophysical indicators, and interdisciplinary assessment teams could ensure these indicators receive adequate consideration.

Keywords: aquatic protected areas; community management; fish conservation; freshwater conservation; inland fisheries; monitoring and evaluation

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1. Introduction

The protection of aquatic habitats and species has gained momentum around the world through the growing establishment of marine protected areas (MPAs) [1–3] and, to a lesser extent, freshwater protected areas (FPAs) [4]. Following the establishment of such aquatic protected areas (APAs) in freshwater or marine habitats, monitoring and evaluation are required to determine whether they are effectively meeting their intended objectives. Such evaluation makes it possible to learn from management errors or challenges, and determine factors that contribute to APA success [1]. While several initiatives have developed methods for monitoring and evaluating the effectiveness of terrestrial and marine protected areas e.g., [5–8], similar efforts and resources are lacking for freshwater. This presents an opportunity to review methods of evaluating MPAs to find lessons that may be transferred to FPAs [9].

To date, much research on the effectiveness of FPAs has focused on whether existing or proposed networks of terrestrial protected areas offer adequate protection of the freshwater biodiversity found within their boundaries [10–18]. Site selection for terrestrial protected areas is often opportunistic, and they are typically designed for terrestrial rather than aquatic species, sometimes by using rivers to delineate boundaries [19]. In some cases, terrestrial protected areas allow harvest of fish species or stocking of alien fish species [20]. As a result, freshwater biodiversity may not be well protected or represented [11], highlighting the importance of designing and evaluating FPAs specifically for aquatic conservation.

In contrast to marine systems, the linearity and continuity of river systems present challenges of scale for the design of freshwater protection [21]. As discrete refuges designated within a continuous system, riverine FPAs typically offer fragmentary protection. Therefore, FPA design and site selection must take into account the larger connected riverscape, as well as how freshwater realms are connected to marine and terrestrial realms [22–24]. Connectivity also makes freshwater systems more vulnerable to upstream threats, such as pollution or habitat degradation, and can limit the effectiveness of FPAs to address the impact of threats beyond their borders [25–27]. This should inform realistic expectations of what FPAs are designed to accomplish. Those that primarily restrict fishing activity may help alleviate the threat of overharvest on fish populations [28], but might have little impact on other threats, which could influence their effectiveness. In recognition of these important spatial considerations, managers designing evaluations of FPA effectiveness may need to incorporate external threat assessments and comparative monitoring at sites upstream and downstream of FPA boundaries. Once FPAs are established, there has been little guidance to date for monitoring how well these areas are achieving their goals and objectives.

1.1. Community Participation in Management of Aquatic Protected Areas in Southeast Asia

This literature review was undertaken as part of an effort to address a resource gap for evaluating FPA effectiveness. It focuses particularly on FPAs that are established to conserve and manage fish populations and that are managed by local communities, often through a co-management strategy in which responsibility for the protected areas is shared between communities and government officials. Engaging local people to designate and enforce community-managed protected areas has emerged as a conservation strategy in tropical marine ecosystems [29,30] as well as freshwater environments [9,31,32]. Community participation in resource management is prevalent in Southeast Asia, including the Lower Mekong Basin (LMB), often linked to the process of decentralization [28,32,33], and has been applied to the management of coastal areas, mangrove forests, wetlands, and riverine deep pools [33–36]. Many countries have adopted community based or co-managed FPAs for fishes in river and lake environments, which go by various names, including Community Conserved Zones in the Philippines [32], Fish Conservation Areas in Cambodia [37], Fish Conservation Zones in Lao People’s Democratic Republic [31,38], reserves in Thailand [39], and Freshwater Fish Safe Zones in India [40]. Freshwater protected areas may also be created by “merit zones” that prohibit killing near Buddhist temples in the region [41]. In the LMB, FPAs are established to meet a variety of objectives based on community needs and the goals of facilitating organizations and government agencies, including improved food security, alleviating poverty, and conserving biodiversity [36]. The highly localized scope of community-managed FPAs has rendered these efforts largely invisible to the broader conservation community [20], and underscores the need for increased attention on this topic. Although guidelines had previously been developed for establishing FPAs through a participatory approach [42], until recently few guidelines or resources existed for evaluating these FPAs following establishment. Frameworks developed for evaluating the effectiveness of MPAs can serve as models for a freshwater context. In particular, Pomeroy, et al. [43] published the widely used guide “How is your MPA doing? A Guidebook of Natural and Social Indicators for Evaluating Marine Protected Area Management Effectiveness” (HIYMPAD, Example 1).

1.2. Example 1. How Is Your MPA Doing? A Guidebook of Natural and Social Indicators for Evaluating Marine Protected Area Management Effectiveness

The HIYMPAD Guidebook is a resource to assist MPA managers and practitioners developed by the International Union for the Conservation of Nature (IUCN), the World Wide Fund for Nature (WWF) and the National Oceanic and Atmospheric Administration (NOAA) through the MPA Management Effectiveness Initiative between 2001 and 2003 [43]. The guidebook was intended to provide guidance for site-specific MPA evaluations, and was not designed to provide standardized comparative data between sites [44].

The guidebook was developed through a stepwise, participatory approach. First, a global survey was conducted of MPA goals and objectives, which were categorized as either biophysical, socioeconomic, or governance. The authors then identified more than 130 indicators related to these goals and objectives. This draft set of goals, objectives, and indicators was peer-reviewed, then refined at a workshop with 35 experts from 17 countries into a revised list of 52 indicators. The list of indicators was further pared down to 44, and definitions, methods of measurement, and guidelines for analysis were written and submitted to two rounds of peer-review. The first draft of the guidebook was reviewed by experts and practitioners at volunteer pilot sites and revised. A training workshop was held for representatives from 20 pilot projects, and the second draft of the guidebook was field tested at these sites over a period of five months. The authors highlighted the value of field testing under real-world conditions, which ensured that the guidebook was practical and useful. Based on feedback from the field testing, the guidebook was revised a final time and introduced at the 5th World Parks Congress in Durban, South Africa, in 2003. Since its development, the HIYMPAD guidebook has been used at more than 200 MPA sites.

1.3. Developing Guidelines for Assessing Fish Conservation Zones in Lao PDR

Although HIYMPAD provides a useful reference, FPAs in the LMB are typically much smaller than MPAs and require a tailored approach to monitoring freshwater habitats. The emphasis on local management in the LMB suggests that FPA evaluations should include community participation, and therefore the community's understanding of FPA objectives as well as their available resources and expertise should be taken into account when selecting appropriate effectiveness indicators to measure. This literature review was conducted as part of a project to create a guidebook "Guidelines for Assessing Fish Conservation Zones in Lao PDR" [45] modeled after HIYMPAD [43] specifically for evaluating community co-managed FPAs in Lao PDR, with relevance to the broader LMB, as part of a grant from the Critical Ecosystem Partnership Fund. Using the indicators and methods included in HIYMPAD as a starting point (Example 1), the results of the preliminary literature review were synthesized into a list of 51 potential indicators most relevant for monitoring community co-managed FPAs in Lao PDR. This list was refined to 20 indicators at a stakeholder workshop in 2016, which were then described in a draft guidebook along with instructions for FPA assessments and suggested methods for each indicator. The draft guidebook was field tested at three FPA locations in Lao PDR in partnership with WWF Laos and the Japanese International Volunteer Center and submitted for expert review. The final revised guidebook included 21 indicators evenly divided among biophysical, socioeconomic and governance indicators, and was released at a training workshop in Vientiane, Lao PDR, in May 2019 [45].

1.4. Indicators of Effectiveness for Aquatic Protected Areas

According to Hockings, et al. [46], management effectiveness evaluations can investigate protected area design, the function of management systems and processes, and the achievement of protected area objectives (i.e., outcomes). Outcomes can be evaluated by examining indicators, which are specific qualitative or quantitative variables directly linked to management goals and objectives, and are used to measure the status and trends of management effectiveness [43,47]. A good indicator is both relevant to the objective and effective (i.e., accurate and precise) [47], but is also easily measured and can predict changes that can be influenced by management [48]. Clear goals and objectives, as defined during the establishment of a protected area and agreed to by stakeholders, are essential to ensure that selected indicators will be tied directly to the results of resource management decisions [48].

Understanding the effectiveness of a protected area is multifaceted, and a diverse suite of indicators is required for assessment. APA effectiveness cannot be measured by any single indicator, but is better suited to a holistic approach through the measurement of multiple types of indicators, such as through a "scorecard" evaluation [8]. Design indicators can assess the context (i.e., values, threats, policy environment, stakeholders) and planning stages (i.e., protected area design and planning) of APAs. Process indicators that relate to the function of management can assess inputs (i.e., resources) and processes (i.e., how management is conducted). Outcome indicators that relate to achieving management objectives can assess management outputs (i.e., programs, actions, products, or services) and outcomes (i.e., whether long-term objectives were met) [46]. Evaluation of management outcomes can be further categorized by discipline (e.g., biophysical, socioeconomic, and governance) [43]. This review utilizes these three discipline categories provided by Pomeroy, Parks and Watson [43], and primarily focuses on indicators of APA outcomes, along with some process indicators related to inputs.

Selecting appropriate indicators is key to developing a useful monitoring framework. In general, indicators should be measurable, precise, consistent, sensitive, and simple [43,49], and should be relevant to the assessment of interest [47]. If protected areas are managed by local communities, as with FPAs in the LMB, there is the additional need for indicators to be effectively communicated and interpreted in non-technical language [50]. Indicators can be described by various metrics or measurements that have a unit of scale [47], and data for these metrics may be gathered using numerous methodologies. For example, the biophysical indicator "species abundance" can be measured with the metric of "number of fish per trap per hour," which can be obtained through the methodology of fish trap surveys.

Given the lack of published literature related to appropriate indicators and methods for monitoring and evaluating community-managed FPAs, the objectives of this review are to (1) explore the process of selecting and measuring indicators of effectiveness in MPAs and FPAs, and (2) discuss considerations for measuring relevant indicators in the context of freshwater community-managed FPAs in the LMB.

2. Methods

A broad suite of indicators of APA management effectiveness was compiled in order to develop a more specific list of those most relevant to FPAs in the LMB. The research database Web of Science was used to conduct an initial search in August 2015 for scientific journal articles related to assessments of aquatic protected areas. Search terms included "Fish Conservation Zones", "freshwater AND reserves", "marine AND reserves", "freshwater AND protected AND area", "marine AND protected AND area", "indicators AND effectiveness AND fish AND reserves"; all were typed in English and there were no specific inclusion or exclusion criteria. In addition, the references of most articles were examined for further relevant articles, and we included articles from personal archives. The review was updated in September 2020 using a search in Google Scholar with the same search terms for papers published from 2015–2020. A total of 187 journal articles and reports was identified in this way; of these, 155 were reviewed. Priority was given to articles describing research conducted in Southeast Asia, or research that measured indicators in an FPA. Due to the large number of studies published on MPAs, emphasis was given to review articles. Each article was read by at least one of three reviewers who assessed its relevance. The main methodologies and key findings were recorded in a document and summarized in a table. In particular, reviewers noted whether the article described specific indicators of APA effectiveness and how those indicators were measured.

3. Results

Of the papers reviewed, 73 discussed MPAs, 75 discussed FPAs and general freshwater conservation, four papers discussed both marine and freshwater protection, and three papers discussed terrestrial protected areas without a freshwater focus. The majority of freshwater papers that focused on a particular ecosystem included riverine systems and watersheds (33 papers), while a smaller number focused on lake, wetland, or floodplain environments (14 papers). Of the freshwater papers reviewed, 21 (28%) described or measured indicators in FPAs or freshwater environments in terrestrial protected areas: 18 papers included ecological indicators, and three papers included socioeconomic or governance indicators. The remaining freshwater publications discussed conservation priorities, the effectiveness of terrestrial protected areas in conserving freshwater biodiversity, and design or site selection of FPAs.

4. Discussion

4.1. Lessons Learned in the Indicator Selection Process

Of primary importance, APA evaluations should include indicators that are directly linked to a management objective, the management process, or a research question [47,51]. This requires that APA objectives be explicitly defined, ideally when the APA is established, as absent or vague management objectives present a challenge to evaluating effectiveness [52,53]. However, clearly measurable objectives make an APA vulnerable to disappointment or criticism if it fails to meet them, which may be one reason vague management objectives persist [54]. Objectives not explicitly included in an APA management plan may also be included in an assessment if they are important to stakeholders or influence stakeholder perceptions of APA effectiveness. Some authors advise selecting indicators using a participatory approach that allows for stakeholder input [55,56], or assesses indicator accessibility or relevance to stakeholders [50,52], in order to make the results of evaluations more meaningful to resource users. Indicator relevance to the scientific community can be determined based on its frequency of use in APA evaluations and publications [57], while indicator effectiveness can be determined based on how frequently it yields significant results across studies [47]. These criteria of relevance and effectiveness can be used to broadly evaluate whether a given indicator is useful, but its effectiveness at measuring the success of a particular APA will depend on local factors.

There is no one best set of indicators to measure, as indicators should be context-specific [56]. An initial search may yield dozens of possible indicators, which are typically pared down using multiple rounds of discussion and selection into a relevant and realistic subset (Example 1). Some suggest that a set of 10–20 indicators in an evaluation framework is a reasonable compromise between effort and accuracy [55,56]. Ultimately, indicators need to be tested in the field and the results reviewed in order to determine whether a given indicator is providing relevant information about APA performance that can guide management. Indicators related to tangible management inputs and outputs may be more relevant to newer APAs, while those related to ecological or social outcomes may be more relevant to older APAs, based on increased expectations for protected area performance over time [56]. Although not often discussed in the reviewed documents, the relative costs of methods related to each indicator are also an important consideration (e.g., [58]).

4.2. Review of Indicators

Here we discuss some of the most frequently measured indicators encountered in the literature review, as well as others that were highlighted as important to APA assessments. It should be qualified that these are not necessarily the most appropriate indicators for FPAs. Pelletier et al. [47] found that the most widely used indicators were not necessarily the most effective, indicating a potential for publication bias, but also the need for careful consideration of context-specific indicators. We link each indicator to relevant APA objectives (Table 1) and address potential concerns about effectiveness and relevance of each with respect to community-managed FPAs (Table 2). We also provide a general difficulty rating for each indicator based on how challenging it is to measure compared to other indicators in the same category (Table 2), although it should be noted that both simpler and more complex methodologies may be available for a given indicator.

Table 1. List of performance indicators linked to common Aquatic Protected Area objectives.

Category	APA Objective	Example Indicators	Example Relationship between Indicator and Objective
Biophysical	Increase the abundance of a focal species	Species abundance	Is the abundance of the focal species increasing over time inside the APA?
		Focal species population structure	What proportion of the focal species population inside the APA is of reproductive age?
	Increase total abundance of all fishes	Taxon abundance	Is the abundance of all fishes (or a group of fishes) increasing over time inside the APA?
	Protect or increase the biodiversity of aquatic species	Composition and structure of the community	Are various measures of biodiversity, such as richness, evenness and dominance, changing over time inside the APA?
	Protect critical habitats (e.g., spawning or rearing habitat)	Habitat distribution and complexity	Does the distribution of habitats in the APA include the critical habitat of interest? What is the quality of that habitat?
		Water quality	Is the water in the APA of sufficient quality for aquatic species to survive?
		Composition and structure of the community	How are species distributed among habitats in the APA?
		Focal species population structure	Are reproductive adults found in spawning habitats? Are juveniles found in rearing habitats?
Socioeconomic	Increase community fish catches near the APA through spillover	Fishery spillover: Species/Taxon abundance *	Is the abundance of the targeted fish species/group increasing over time inside the APA, therefore providing a source of fish to "spill over"?
		Fishery spillover: Type, level, and return on fishing effort *	Are members of the community catching the targeted fish species/group outside of the APA? Is the community's return on fishing effort outside the APA increasing over time, indicative of spillover?
		Local aquatic resource use patterns	Have community fishing patterns shifted closer to the APA boundary, indicative of spillover?
		Perceptions of local resource harvest or abundance	Do people perceive that fish catches have increased in the community, indicative of spillover? (indirect measurement)
		Perceptions of benefits derived from an APA	Do people perceive that fish catches have increased in the community as a result of the APA, indicative of spillover? (indirect measurement)

Table 1. *Cont.*

Category	APA Objective	Example Indicators	Example Relationship between Indicator and Objective
	Increase community food security	Level of household fish consumption	Are people eating more locally caught wild fish following the establishment of the APA?
		Local aquatic resource use patterns	Do people have more access to fish to eat as a result of increased fishing catches?
		Perceptions of benefits derived from an APA	Do people believe that fish and other aquatic foods are more available as a result of the APA? (indirect measurement)
	Support community livelihoods	Household income distribution by source	How many households are engaged in activities affected by the APA? How important are these activities to their income?
		Local aquatic resource use patterns	Are fishing livelihoods in the community affected by the APA?
		Perceptions of benefits derived from an APA	Do people perceive that their income has increased as a result of the APA? (indirect measurement)
Governance	The APA has sufficient management inputs to achieve its goals	Existence and adoption of a management plan	Are there clear rules and guidelines to guide management of the APA?
		Existence of a decision-making and management body	Is a designated group actively engaging in APA management?
		Availability and allocation of APA administrative resources	Are funding, equipment, and personnel sufficient and effectively distributed to achieve management goals?
	Community members support APA management	Local understanding of APA rules and regulations	Do community members understand and agree with APA rules?
		Level of stakeholder participation and satisfaction in management	Do community members play an active role in APA decision making or management activities? Do they agree with or support APA management decisions or activities?
		Level of resource conflict	Have conflicts arisen among community members or between community members and managers related to dissatisfaction with APA management?
		Perceptions of benefits derived from an APA (socioeconomic indicator)	Is community support of the APA influenced by whether they think they have benefited from the APA?

Table 1. *Cont.*

Category	APA Objective	Example Indicators	Example Relationship between Indicator and Objective
	Good compliance with APA regulations	Local understanding of APA rules and regulations	Are community members aware of and do they understand APA regulations to ensure they are not violating rules inadvertently?
		Level of stakeholder participation and satisfaction in management	Are community members more likely to abide by APA regulations that they helped develop, or that they think are fair?
		Compliance with regulations	How many people are violating the APA regulations, how often, and in what ways?
		Level of resource conflict	Are conflicts between resource users and managers leading to low compliance?

* These indicators should be measured together to provide evidence of spillover.

Table 2. Considerations for measuring common APA effectiveness indicators in a freshwater community management context.

Biophysical Indicators	Considerations for Freshwater	Level of Difficulty to Measure (Relative to Others in the Same Category)
Species/Taxon abundance	Visual census methods may be limited by visibility; air-breathing fish can be censused while surfacing; biomass may be a more effective metric than numeric abundance; in riverine systems, migratory fishes may be censused via fish counting weirs or fykes	High (species)/ Medium (taxon)
Composition and structure of the community	Diversity of freshwater invertebrates may be an indicator of habitat quality	High
Focal species population structure	If focal species are migratory and use the FPA seasonally, the size structure of focal species will shift during the year	High
Water quality	In riverine systems, water quality will be determined in part by upstream and tributary influences, and sampling should account for this water quality gradient	Low
Habitat distribution and complexity	Visual census methods may be limited by visibility; substrate type may be important for fish spawning	Low
Fishery spillover (type, level and return on fishing effort)	The absence of a central fish landing site in many freshwater environments can present challenges to assessing fish catches	Medium

Table 2. *Cont.*

Socioeconomic Indicators	Considerations for Community-Managed FPAs	Level of Difficulty Measure (Relative to Others in the Same Category)
Perceptions of local resource harvest or abundance	This indicator makes use of local ecological knowledge, which can be especially valuable if baseline data on fish catches or fish abundance prior to FPA establishment are lacking	Low
Perceptions of benefits derived from an APA	This indicator can also be used to assess negative impacts of an FPA on communities	Medium
Local aquatic resource use patterns	The absence of a central fish landing site in many freshwater environments can present challenges to assessing freshwater fish catches	Medium
Household income distribution by source	This indicator may be challenging to measure in rural communities that do not keep formal records of income	High
Level of household fish consumption	Wild-caught fish will need to be distinguished from aquaculture fish	Medium
Governance Indicators	**Considerations for Community-Managed FPAs**	**Level of Difficulty to Measure (Relative to Others in the Same Category)**
Existence and adoption of a management plan	FPAs that have received government approval (in a co-management structure) may be more likely to have written regulations or a management plan than those that are entirely community managed	Low
Existence of a decision-making and management body	The function and activities of a management body should ideally also be evaluated	Low
Availability and allocation of APA administrative resources	Community-managed FPAs may be less likely to have a dedicated funding source than government-established protected areas	Low
Level of stakeholder participation and satisfaction in management	Fishers may be more willing to follow FPA regulations if they have participated in developing those regulations; top-down influence by facilitating organizations or government around the FPA establishment process could decrease community participation or satisfaction	Medium
Compliance with regulations	Illegal fishing boats are often smaller, faster, and harder to apprehend in freshwater compared to marine environments; communities may not keep formal records of offenses or surveillance effort	Medium
Local understanding of APA rules and regulations	Community members who participated in the development of FPA regulations will likely be more knowledgeable about those regulations than the rest of the community	Low
Level of resource conflict	There may not be formal channels to document complaints about community-managed FPAs that might exist at government-managed FPAs	High

4.3. Biophysical Indicators

Biophysical indicators were more frequently assessed than socioeconomic and governance indicators in studies of both FPAs and MPAs, rather than the "balanced" evaluation portfolio of all three indicator categories proposed by HIYMPAD [44]. This likely reflects an emphasis on producing biological outcomes that motivates the establishment of APAs as a conservation strategy. Below we discuss the biophysical indicators that were more frequently encountered in available freshwater literature (Table S1): species/taxon abundance, focal species population structure, composition and structure of the community, and water quality. We also discuss the importance of habitat distribution and complexity, and challenges in evaluating spillover.

4.4. Species/Taxon Abundance

This frequently measured indicator [57] relates to one of the most common objectives of APAs, which is to increase the abundance of fishes or other aquatic animals (Table 1). Abundance is particularly important to measure if an APA was established specifically to conserve a focal species of interest (e.g., *Arapaima gigas* in Amazonian freshwater reserves [59]). A focal species may be one of particular conservation or economic importance, or may be selected as an indicator to assess the fish community as a whole [48]. The metric most frequently used for this indicator was relative numeric abundance (number of fish), followed by relative biomass (mass of fish per unit surface area or volume) and density (number of fish per unit surface area or volume). Some studies also measured total abundance and total biomass of all fish or invertebrates combined as a way to evaluate the APA objective of increasing the abundance or biomass of all fish or invertebrates generally (i.e., taxon abundance) [60,61]. Trophic dynamics may influence the abundance of various populations inside an APA depending on whether the species released from fishing pressure are predators, prey, or both [62,63].

Species abundance can be measured using several standard sampling methodologies, which can be tested to directly compare results [58]. While focal species abundance is often measured using visual underwater census techniques in MPAs (Table S1), such techniques are rare in FPAs, except for areas with sufficient visibility [64]. Notably, Koning et al. [39] used snorkel surveys to visually evaluate fish abundance inside and outside of riverine community-managed FPAs in Thailand during the dry season. This metric is often measured in freshwater using other methods such as electrofishing, traps, and gill nets or seine nets. Community members familiar with traditional fishing traps and nets utilized in the LMB [65] could participate in assessment data collection by deploying these gears in a standardized way. Air-breathing fish can also be surveyed when they come to the water surface [59]. Numeric abundance was more frequently used as a metric compared to biomass in freshwater studies, likely because it is easier to count fish than to measure and weigh them. However, an assessment of MPA biophysical indicators by Soykan and Lewison [66] found that measuring biomass can more consistently detect protected area effects than measuring numeric abundance, as it accounts for fish size as well as number. Biomass is also particularly relevant to the conservation of female fishes, whose fecundity can scale allometrically with body size; therefore, allowing female fish to grow inside APAs can provide subsequent benefits to population growth and spillover [67]. As biomass may be a more effective abundance metric [47,61], it bears inclusion in freshwater assessments.

4.5. Composition and Structure of the Community

As a means of measuring diversity, this indicator is frequently used to evaluate APAs that have an objective to protect or increase aquatic biodiversity [57]. Among numerous potential diversity metrics, species richness is by far the most common, likely because it is relatively easy to document the number of species encountered in sampling [68]. In FPAs, most studies focused on fish species diversity, but some also examined other taxa, including macroinvertebrate assemblages [69–71], algae, and macrophytes [70]. For freshwater macroinvertebrates, standard indices such as the species richness of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (EPT) can be used as a general bioindicator of freshwater health [69]. For fishes, this indicator can often be measured using the same methods as species abundance surveys (Table S1), which facilitates data collection.

The literature review also revealed many concerns about using community composition and structure as an indicator, in particular the metric of species richness. Despite its frequent use, species richness is not good at detecting changes in community composition because it can be influenced by the history and size of an area as well as trophic interactions [62,66]. Total species richness also includes both native and non-native species, and therefore may not detect changes from non-native species displacing natives; therefore, native species richness can be used as a metric if invasive species are a concern [17]. Other aspects of diversity to consider include species evenness and dominance, functional diversity, and phylogenetic diversity [66]. Functional diversity can track changes in ecosystem functions based on traits related to trophic level, behavior, habitat use, or physiology, and may reveal changes from protection not detected by traditional abundance or diversity metrics [72,73]. Application of this approach may be limited by available information on functional traits of the fish assemblage, especially in the highly diverse LMB where species-specific information is often lacking, but see [74].

4.6. Focal Species Population Structure

By describing how many individuals in a population of interest fall into different size or age classes, this indicator can help measure how a species is responding to APA protection. The indicator is most relevant to focal species for which the approximate size at reproductive maturity is known. In particular, if an APA objective is to promote spawning or protect spawning individuals, this indicator can provide information on the number of adults of spawning age or size, whether new offspring are adding to the population (births), and how adult abundance is changing over time. Population size distribution has shown a strong relationship with the potential of a protected area to increase population abundance [47]. Researchers in three freshwater studies measured this indicator by comparing size class distributions for focal species, and found more large (and sometimes more small) individuals inside FPAs compared to fished areas [75–77]. Data on population structure are often collected simultaneously with other metrics; however, sampling methods that are size-biased will not provide accurate or complete information on size structure.

Focal species population structure may not be a very informative indicator if used alone, and additional factors such as species abundance and recruitment success, or changes in trophic dynamics or habitat use, may need to be measured to explain observed changes in population structure. The size structure of a focal species may shift seasonally if some or all of the population is migratory, or if there is seasonal recruitment into the population, which should be considered when designing the timing of surveys. This may be especially true in riverine systems where FPAs may be designed to protect migratory species passing through [23]. A more recently used metric for focal species population structure is genetic diversity within that species, which can provide information on genetic isolation of the population, degree of genetic relatedness, and conservation of allelic diversity [78]. Analysis and interpretation of genetic diversity data may require equipment and expertise beyond that of local organizations in the LMB and therefore depend on partnerships with technical experts.

4.7. Water Quality

Water quality parameters were frequently measured in freshwater studies, but often as an explanatory variable for species composition or abundance, rather than a measure of effectiveness of protection, e.g., [79]. If water quality inside an APA is inadequate, then fish populations may not benefit from protected area regulations. Parameters frequently measured included temperature, conductivity, pH, dissolved oxygen, and turbidity or transparency (Table S1). Water quality indicators may be most informative when data are collected before and after protection, as well as both upstream and downstream for linear systems, to clarify whether a difference in water quality occurred prior to

APA establishment, and whether it is an outcome of management actions or changes in external factors. Water quality in freshwater environments may be particularly impacted by runoff, erosion, or pollution.

4.8. Habitat Distribution and Complexity

This indicator is relevant to APA objectives to protect or restore particular habitat types, such as coral reefs and kelp forests in marine environments, or aquatic vegetation and particular spawning substrates in freshwater. Although rarely assessed in the freshwater literature reviewed, but see [64], it is also useful as an explanatory indicator, since differences in fish abundance between sites could be attributable to differences in habitat and structural complexity, rather than protection [80]. Furthermore, since baseline data collected before protected area establishment are rare, most studies compare APAs to control sites, which may have differences in habitat quality and complexity that influence the comparison. Protected area sites are not selected randomly, and are often chosen because they contain habitat of relatively good quality or diversity [81]. This should inform selection of similar control sites, but such considerations are not always apparent in published studies. Sarkar, et al. [82] compared a riverine protected area to an unprotected reach downstream and found greater species richness and abundance inside the FPA, but also more diverse and less modified habitats, making it difficult to identify whether protection or habitat was the main driver. Similarly, Srinoparatwatana and Hyndes [76] found an inconsistent effect to protection on fish abundance inside and outside of a wetland FPA. In this study, the protected area had higher turbidity due to sediment dredging, which appeared to cause a decrease in aquatic vegetation and may have impacted fish populations. Neither of these studies specifically incorporated data on physical habitat aspects such as woody debris, submerged vegetation, or channel structure, but both noted that differences in these features may have played a role in the results. Therefore, it is valuable for assessments to compare the similarity of habitat inside and outside of a protected area, e.g., [83], and account for interactions to distinguish changes in habitat quality and complexity (e.g., algal cover or large woody debris) as a result of protection versus pre-existing differences in habitat between sites. To make these distinctions, it is ideal to have datasets of habitat quality before and after protection, similar to water quality indicators.

4.9. Spillover

The movement of fishes beyond APA boundaries and their contribution to nearby fisheries (termed "spillover"), is often stated as an expected benefit to fishers as a result of APA establishment. In a review of 85 MPA articles published from 1981–2014, spillover was reported in 80% of empirical studies [84]. In contrast, our review found a single example of FPA assessments using this indicator [75]. Fish movement beyond APA boundaries may be evaluated indirectly by measuring the indicator "species abundance" inside and outside of the APA, or evaluated directly through the use of fish tagging studies. Potential spillover benefits to fisheries may be documented using the indicator "type, level and return on fishing effort" in that increased fishing catches outside the FPA is the desired objective, and spillover is the presumed process by which this objective is achieved. For APAs to benefit nearby fisheries, the target species cannot be too mobile or susceptible to fishing [1], but it cannot be so sedentary that it never "spills" out to other areas (via larvae or adults). The potential contribution of adults to "spill" outside a protected area can be examined using mark-recapture or telemetry techniques, which can also provide information on whether there is a mismatch between the normal "activity space" of fish and the size of the protected area [85]. Research in MPA systems has found that adult fish spillover typically occurs on modest scales, at an average of 800 m away from protected area boundaries [86] based indirectly on abundances (rather than fisheries catch). However, if fishing effort is concentrated around the boundaries of a reserve, catch data may indicate higher spillover than that documented by abundance surveys alone, as fishing will mask increases in abundance by removing fish from the population.

Halpern et al. [86] emphasize that the existence of spillover does not necessarily mean that fishers will experience economic benefits, because they may have to exert more effort and cost, or may have fewer fishing opportunities with an APA in place. Thus, studies that measure spillover based on abundance metrics inside and outside of an APA may not actually measure benefits to fisheries. Di Lorenzo et al. [84] propose to differentiate the terms "ecological spillover" from the subset "fishery spillover" (the fraction that more directly impacts fisheries yields and revenues) to improve clarity in dialogues with stakeholders and determine appropriate monitoring approaches (e.g., visual census, tagging, and catch data). They suggest several steps for evaluating fishery spillover and conclude that few studies actually assess this indicator of management objectives, in agreement with the findings of this review. This could be in part because effectively demonstrating spillover requires measuring an increase in fish abundance inside an APA, movement of fish from inside to outside of the APA, and increased fish catches outside the APA (Table 1). This indicator is relevant to the LMB, as fishery benefits are often cited as reasons for establishing community-managed FPAs [36]. When conducting effectiveness assessments, it should be clarified whether fishery spillover is a desired objective of an FPA and whether this objective is being explicitly assessed through the inclusion of certain indicators.

4.10. Socioeconomic Indicators

The design of many APAs is to conserve aquatic life by restricting human activity, especially fishing, which could have negative consequences for fishing-dependent communities, particularly in the short term. At the same time, desired benefits of community-managed APAs often include improved food security or livelihoods over the long-term. Therefore, evaluating both positive and negative impacts of APAs on human communities is of equal importance as evaluating impacts on the aquatic ecosystem, and is particularly relevant to community-managed FPAs in the LMB. However, socioeconomic indicators tend to be the least studied of the three categories in APA evaluations [47,50,52], highlighting the need for more effort, which would be aided by the development of more standardized methodologies and the inclusion of social scientists in assessment teams. Failure to take social dimensions into account can erode the legitimacy of an APA and undermine governance effectiveness. Socioeconomic impacts of APAs may be tangible, such as effects on resource access or livelihoods, or intangible, such as effects on culture or cultural heritage, way of life, or sense of place [87]. Socioeconomic impacts are likely to vary by context, underscoring the importance of evaluating APAs individually [88].

Unlike measuring biophysical indicators, which may require distinct methods in freshwater and marine realms to accommodate differences in the physical environment, the same methods can be used to assess the human dimensions of APA effectiveness regardless of setting (Table S1) [9], and many are discussed in Bunce et al. [89]. Few studies were found that assessed socioeconomic indicators in FPAs [31,32,35]; therefore, the majority of the review draws on examples from MPAs. The most frequently encountered or relevant socioeconomic indicators discussed here include perceptions of local resource harvest or abundance, perception of benefits derived from an APA, local aquatic resource use patterns, household income distribution by source, and level of household fish consumption.

4.11. Perceptions of Local Resource Harvest or Abundance

This indicator assesses local ecological knowledge by asking fishers about the quantity or composition of their catch, and how these have changed over time. It may also be measured by asking communities whether they think fish populations in general have changed in number [59]. The frequent use of this indicator likely reflects its connection to the common APA objective to improve fish abundance, and thereby improve fishing catches for local people through fishery spillover (Table 1). Local ecological knowledge is a method commonly used for freshwater conservation studies in the LMB, and has been used to determine when freshwater fish of conservation interest were last captured, fisher perceptions of the overall status of each species [90], trends in abundance and body size, and critical habitats and threats facing species of interest [91]. This indicator has also been used to evaluate co-managed FPAs in Lao PDR by asking fishers to identify fish species caught in the past 12 months based on photos and Lao common names, providing an indirect measurement of species richness [92].

Relying on community perceptions and recall as an indirect measure of fishing catches requires fewer resources than measuring fish catch directly, and can be helpful for understanding historical conditions before the establishment of an APA, for which fish abundance data are often lacking [93,94]. A drawback of this perception-based indicator is that it is subjective and relies on memory, and not all community members will have the same quality of recall. Perceptions can also be biased by the respondent's latest recollection, i.e., "shifting baselines" [60]. Perceptions of fishing catches or fish abundances should ideally be corroborated by fish catch monitoring approaches, such as those discussed under *Local Aquatic Resource Use Patterns* below [95] or fisheries independent methods described in the *Biophysical Indicators* section [96]. Perceptions of biophysical conditions may not actually reflect those conditions; however, they can provide insights into community thoughts and behavior, which can inform the design of management and outreach strategies [96].

4.12. Perceptions of Benefits Derived from an APA

A similar indicator to the one just described is asking whether communities believe the protected area is responsible for producing any positive outcomes they perceive, such as increased fish catches or abundances, or other livelihood benefits like increased tourism. This indicator has been used to assess FPAs in Lao PDR [31], and is related to the objective of obtaining community support for FPA management, as community members may be more likely to support an FPA if they believe it is providing benefits. Perceived benefits may be tangible, like allowing fished species to reproduce, or intangible, such as a feeling of local control over resource use [30]. This indicator also presents an opportunity to ask about negative impacts that communities believe they have experienced directly as a result of the APA, such as impacts to fishing activities, income, or food availability [30,97], and can be used to determine whether benefits or impacts are shared equitably. Gathering information about factors other than APA establishment that may influence perceived benefits can help interpret results of this indicator. While assessing perceptions is cost effective and draws on local knowledge, perceptions will reflect the participants' interests and concerns [30], and should ideally be corroborated with empirical data, as discussed above.

4.13. Local Aquatic Resource Use Patterns

This indicator seeks to characterize human interactions with the aquatic environment, particularly in relation to an APA. For community-managed APAs, this typically includes assessing the locations, timing, and methods of fishing practices, but can also characterize other activities related to the APA or aquatic environment, such as tourism [98,99], recreation, or spiritual activities. Given that APAs typically restrict or regulate human activities within their borders, this indicator can help determine whether the protected area has disrupted normal community practices. It can also be used to understand which habitats are fished most frequently [60], and whether fishing activity has been displaced or reduced by an APA. Similar to perceptions of local resource harvest, this indicator is often measured to provide evidence as to whether an APA is contributing to improved fish catches through fishery spillover, and should take gender into account, as men and women often play different roles in LMB fisheries. [37,100]. Beyond perceptions, aquatic resource use patterns may be used similarly to the HYIMPAD biophysical indicator "type, level and return on fishing effort" to collect quantitative measures of fish catch, whether through questionnaires and surveys [101], or through fish catch monitoring [95]. While collecting fish catch data can be time and resource intensive, especially because freshwater fisheries may be dispersed without a central landing site, the results can be used to corroborate community perceptions. Without baseline data, it may be challenging to ascribe changes in fish catch directly to an APA. One option is to assess fish catches in similar communities that do not live near an APA for comparison [101]. Measuring fishing activity is related to the APA objective of supporting community livelihoods, whereas measuring fish catches is related to the objective of improving fish catches or food security (Table 1).

4.14. Household Income Distribution by Source

This indicator typically assesses a household's various livelihood activities and how much each contributes to overall income. It is related to APA objectives to support community livelihoods, increase incomes, or reduce poverty. In terms of social safeguards, measuring this indicator can determine the proportion of households that depend directly on aquatic resources for their livelihoods, and therefore may be adversely affected by APA regulations. This indicator can also be used to measure APA benefits if certain livelihoods are specifically linked to the APA, such as patrolling or tourism. Assessing income can help determine the overall economic condition of the community, such as the proportion of households living in poverty [98], while determining a household's dependence on particular activities can be used to assess their vulnerability to poverty [101]. A lack of diversification of income sources, particularly a high dependence on fishing, can make a community more vulnerable to negative impacts from APA resource restrictions [55]. Poverty may drive local people to exploit natural resources, even in protected areas. Measuring household income distribution can help assess whether alternative income generating activities are helping to alleviate poverty conditions [98], or how equitably the financial benefits or impacts from an APA or project are distributed in a community [101].

A key challenge to using this indicator in the LMB is that income data may be difficult to obtain from rural households [55], which may not keep detailed financial records, and self-reported income data may consist of general estimates. This indicator should examine the contribution not just of capture fisheries to household income, but also fish processing and fish trading [60], which are roles often performed by women. If households report an increase in income from fishing-based activities following APA establishment, it would be important to validate whether the APA has in fact contributed to increased fish abundance outside of the APA boundaries or increased fishing catches by measuring relevant biophysical indicators related to spillover. Baseline data on incomes prior to APA establishment would also be required.

4.15. Level of Household Fish Consumption

Although not frequently measured in APA assessments, this indicator is relevant to the APA objective of increasing food security for local people through fishery spillover, which is a common objective of FPAs in the LMB [36]. Therefore, some measure of fish consumption or access to aquatic food bears inclusion in the assessment of such FPAs. When measuring this indicator, care is needed to distinguish wild-caught fish from aquaculture fish, as only fish caught from the same environment as the FPA can provide evidence of FPA effects. Likewise, it is important to document the source of the wild caught fish, which may be transported for sale in markets from distant locations. Household fish consumption is frequently measured in community interview surveys in the LMB, where local people have some of the highest levels of per capita freshwater fish consumption in the world [102]. The related HIYMPAD indicator "Perceptions of seafood availability" is an indirect measurement of fish consumption, and might include asking community members whether they think more fish are available in local markets following APA establishment [56].

4.16. Governance Indicators

The function of an APA is the result of management decisions and processes; therefore, measuring governance indicators is important for evaluating APA effectiveness. Many governance indicators assess the inputs and processes that contribute to the adequacy and function of APA management activities, which play a crucial role in achieving desired outcomes [103]. Governance is highly relevant to the function of community-managed APAs, which require community stakeholders to play an active role in the management process. Only two studies were found that evaluated governance indicators in FPAs [32,104]; therefore, most examples are from evaluations of MPAs. Similar to those described for socioeconomic indicators, methods used to evaluate governance indicators included interviews with key stakeholder groups, as well as direct observations and examination of secondary data sources, such as logbooks, reports, ordinances, or photographs (Table S1). Such documents may be tangible outputs of management, and should not be confused with management outcomes, which can be harder to assess [105]. The frequently measured indicators described here relate to planning and inputs (e.g., existence and adoption of a management plan, existence of a decision-making and management body, availability and allocation of APA administrative resources), the management process (e.g., level of stakeholder participation and satisfaction in management) and management outcomes (e.g., compliance with regulations, local understanding of APA rules and regulations, level of resource conflict).

4.17. Planning and Input Indicators

Three related planning and input indicators are frequently measured to assess the administrative effectiveness of an APA. *Existence and Adoption of a Management Plan* refers to a foundational document that guides APA operations, and may include goals, rules, and regulations for resource users, and a strategic plan with defined activities. In the LMB, a formal plan may be more likely to exist for FPAs that require government approval through a co-management framework. Although a plan may exist, community members may not be aware of its existence, which can be evaluated by measuring separate indicators about local understanding of regulations [98]. A related indicator is the *Existence of a Decision-making and Management Body*, which could involve identifying the management board of the APA and its related committees or individuals who are responsible for carrying out the management plan. The function of the management body can be further evaluated by assessing its activities, such as those related to planning, monitoring, managing fee systems, enforcement, and education or outreach [60]. Finally, *Availability and Allocation of APA Administrative Resources* evaluates key inputs required for an APA to function. Insufficient funding and capacity have often been cited as a primary reason for APA failure [106,107]. An assessment can determine whether an APA's budget is sufficient to meet its expenses, as well as current sources of funding and their sustainability [55,60]. Human resources may include the number of management personnel [55,108], who may serve in an informal capacity at community-managed FPAs, while equipment resources may include patrol boats, boundary markers, and signs [109].

These three elements (a set of management regulations, a group designated to make decisions, and sufficient resources to carry out management activities) have been suggested as the minimum requirements for a protected area to function as a governance and management tool [109]. However, Fox et al. [44] caution that evaluating the existence of necessary APA inputs may not be sufficient to determine if they are functioning effectively. As such, indicators of governance processes and outcomes should also be included in an APA evaluation. However, a global review of MPAs by Gill, et al. [110] found staff capacity to be the most important variable in explaining MPA ecological outcomes, followed by budget capacity, highlighting that inputs and resources are indeed important to carry out key management activities. This is particularly relevant to community-managed FPAs in the LMB, which are often established without a long-term plan for financially supporting management activities.

4.18. Level of Stakeholder Participation and Satisfaction in Management

Studies have repeatedly identified stakeholder participation and satisfaction in management as crucial contributors to APA success and sustainability [94,96,97,106,108,109,111], as they are related to the APA objective of obtaining community support for management. This indicator encompasses both the APA management process (or the extent to which stakeholders can engage in the process of management) and management outcomes (namely, to what extent community members agree with and support the decisions made during the management process). A review of MPA literature by Gallacher et al. [57] found this to be the most frequently measured governance indicator, and the second most frequently measured indicator overall. Actively involving stakeholders in APA design and management, especially resource users such as fishers, can lead to better satisfaction and compliance with regulations [96], and is critical to the function of community-managed APAs. Outlining clear channels for participation, as well as rights and duties for all engaged stakeholders, can help facilitate community involvement in achieving conservation objectives [98]. In the absence of adequate avenues for stakeholder participation, more management time and effort may be needed to resolve conflicts [99]. If participation is low, potential barriers and incentives for participation can be considered [55].

Community satisfaction can be assessed by asking respondents whether they have a positive or negative opinion of a protected area and why [112], or whether they believe the regulations of an APA were established in a participatory way [60]. This should take into account whether people are satisfied with the quality of participation, including factors like opportunities for input and influence, information exchange, fairness, and transparency [96], as well as continuity of participation [113]. Perceptions about the quality of participation can lead to similar perceptions of APA performance [30,96] and can influence community support: Bennett, et al. [114] found that fishers' perceptions of good governance and social impacts were the strongest predictors of support for MPAs. The authors note that community support can help APAs persist over the long-term, which can lead to better ecological outcomes. While strong local leadership and social networks can play an important role in building community support for an APA [32,55,115], it should be considered whether individuals other than community leaders are also engaged in decision making [30]. Community support may be affected by how common APAs are or how long they have been established in a region, which influences how much time positive or negative impacts have had to accrue [116]. This indicator is relevant to the LMB, where FPAs are often community managed in principle, but influence of facilitating organizations in establishment could result in elements of a top-down process that may reduce community participation and satisfaction with management.

4.19. Compliance with Regulations

This indicator assesses the extent to which APA rules are being followed, and can measure who is breaking the rules, how often, and in what ways. Modeling suggests that high levels of poaching, or non-compliance, can negate the biological or fishery benefits of APAs as conservation tools [117]; therefore, compliance is viewed as an important indicator of whether an APA can function to meet its other objectives, or merely exists as a "paper park". Direct assessments of compliance can include reviewing officially documented instances of rule violations [118], although this may be more indicative of enforcement strength than compliance [119]. Ideally, detected offences should be standardized by surveillance effort [109], which may take special effort to document for community-managed FPAs if patrol records are not formally kept.

In a review of publications on MPA compliance, Bergseth, et al. [120] found that empirical studies to measure compliance levels are rare compared to theoretical or policy-based assessments, and those that did obtain data mostly used indirect measures such as questioning stakeholders about levels of compliance. The study also found compliance to be a strong predictor of ecological response, and suggested more work is needed to understand the factors that drive compliance e.g., [121]. Community perceptions of compliance can help assess the level of poaching or illegal fishing that was not officially documented [94,122]. Identifying patterns in non-compliance can also help optimize patrolling efforts to focus on locations or time periods in which violations are most likely [123]. However, detection of illegal efforts is just one part of effective enforcement, which also includes arrest, prosecution, and conviction of rule violators—if these components are not also effective, then enforcement may not deter rule violations [109]. It can be more expensive and challenging to monitor compliance in freshwater compared to marine environments because vessels are often smaller, meaning illegal fishers can disappear more quickly than larger vessels in marine systems, which necessitates increased monitoring [26].

4.20. Local Understanding of APA Rules and Regulations

This indicator measures community awareness and familiarity with an APA and its rules. Local understanding of regulations is frequently measured, e.g., [57], because it is related to APA objectives of good compliance and community support for management: community members cannot be expected to comply with or agree with APA regulations if they do not know what the regulations are. For evaluating newly established APAs, a first step can be determining whether community members know that the APA exists, where it is located, and what its purpose is. This awareness will likely be higher if community members were actively involved in the APA establishment process [30]. Further questioning can ascertain whether community members are familiar with particular rules and penalties or consequences for violating those rules [60]. However, community knowledge of APA rules does not necessarily imply they agree with or support them. This indicator can be measured along with community satisfaction with management to understand whether regulations are perceived as reasonable and fair.

4.21. Level of Resource Conflict

This indicator seeks to evaluate the extent of conflicts or disagreements of interests and ideas that may result from the establishment or management of an APA. It is related to APA objectives of community support for management and good compliance with regulations. Conflict is often cited as a major challenge to APA effectiveness [31,108] that needs to be addressed in order for management to be sustained, and has frequently been measured in MPA evaluations [57]. APA establishment has the potential to generate conflict if not done in an inclusive and participatory way, as restrictions on resource access can negatively impact community members with limited livelihood options [94]. Once established, ambiguous APA regulations and weak communication channels can create conflict and decrease management effectiveness [98]. Conflicts can also arise between resource users related to the use of destructive fishing gear; fishing activities of "outsiders," which could include industrial or commercial fishing [94,98]; interactions between fishers and other resource uses, such as tourism [60]; or unequal distribution of benefits from an APA, such as a limited group benefiting from ecotourism [94]. This indicator can be difficult to evaluate because it requires understanding the context and stakeholders involved to identify the issues at stake. Marques, Ramos, Caeiro and Costa [50] measured conflict based on the number of complaints addressed to the APA management agency; however, a formal complaint mechanism may not exist for community-managed FPAs. Evaluations can also look at whether conflict management practices are in place, and whether these are sustained or decline over time [94].

4.22. Considerations for Designing Assessments of FPAs in the LMB

This review highlighted several important considerations for the design of FPA assessments. Fox et al. [44] found one drawback of the HIYMPAD framework is that data were often not collected in quantitative or standardized ways, making it difficult to draw comparisons between locations or times. Data collected in narrative fashion require re-parameterizing into quantitative data for metadata assessments. Furthermore, the HIYMPAD framework often provided more than one methodology to measure an indicator, which provides flexibility but complicates comparisons. The authors concluded that more specific and standardized monitoring protocols would make the outputs of this framework more actionable and comparable. Likewise, Ojeda-Martinez, et al. [124] evaluated MPA effectiveness studies and recommended using standardized methodologies to facilitate comparisons over temporal and spatial scales. The few metadata analyses that bring together quantitative MPA data, such as species richness and organism size, from many sources have provided useful perspective on overall MPA effectiveness and are often cited as support for their biological benefits [2,62]. These analyses would not be possible without quantitative data collected with somewhat consistent methods. To facilitate future comparisons and metadata analyses in the LMB, standardized data collection methods should be considered when designing FPA assessments.

While most of the biophysical indicators of MPA effectiveness are relevant to FPAs, differences in freshwater physical environments compared to marine settings means that some of the methods used to measure these indicators require particular considerations for the evaluation of FPAs in the LMB (Table 2). For example, visual census techniques commonly used in marine settings are unlikely to be effective in large, turbid freshwater systems, although such techniques may be feasible in smaller headwaters that run clear during the dry season [39]. Assessment surveys using nets and traps could be performed by communities or local organizations in the LMB using standardized local fishing gear [65]. The methods for collecting data on socioeconomic and governance indicators are readily transferable between marine and freshwater environments, since most rely on interviews, document review, and observations. In the LMB, freshwater fisheries are often small scale and dispersed in rural communities without clear landing sites. These challenges may necessitate drawing on or developing methods not already in use in the marine realm to measure indicators related to fish catch, aquatic resource use patterns, household income distribution by source, and compliance with regulations. Governance indicators that measure inputs which are important for the APA establishment process are often less difficult to measure than biophysical or socioeconomic indicators, and therefore provide a logical starting point for assessing community-managed FPAs in the LMB.

Several studies of MPAs have identified a lack of Before-After-Control-Impact [47] assessments that can more clearly define true impacts of protection on both ecological and socioeconomic conditions, due to a lack of data collected before MPA establishment or collecting data that is not conducive to this approach [87,125,126]. Studies of protected areas before and after protection are rare, e.g., [83], but offer valuable insights that could prevent misinterpretation of effectiveness results. Growing interest in implementing FPAs in the LMB and beyond presents a valuable opportunity to collect baseline data before these protected areas are established. Freshwater systems present unique challenges for monitoring compared to marine environments, such as the number and severity of external threats in a highly connected environment [26,27]. Thus, an FPA could appear to be performing poorly not for lack of management effort, but rather due to external stressors [9]. This is relevant in the LMB, where the ecological functions of rivers are threatened by dams, sand mining, and industry, and highlights the importance of collecting relevant explanatory data in assessments to identify the actual effects of FPAs.

5. Conclusions

Our literature review revealed a dearth of evaluations specifically focused on freshwater settings; however, the wealth of lessons learned from the evaluation of MPAs provides a valuable starting point for defining monitoring indicators and designing evaluations for FPAs [125]. Biophysical indicators are much more frequently measured than socioeconomic and governance indicators for both MPAs and FPAs [124], which likely reflects a biological conservation focus to most APA objectives, and a potential lack of explicit socioeconomic objectives in management plans. APAs can nevertheless have profound effects on the livelihoods and well-being of local communities, and inputs into the governance process can influence ecological outcomes [103]. Thus, evaluations would benefit from focused attention on socioeconomic and governance effectiveness, which is particularly relevant for community-managed FPAs in the LMB, where community members rely heavily on freshwater resources and play a large role in FPA management. It is also, therefore, important to consider community participation in designing and implementing FPA assessments. Using an interdisciplinary approach to assessment and including social scientists on assessment teams would ensure that these indicators receive consideration.

As with MPAs, FPAs show promise for benefiting small-scale fisheries in places where single-species management may not be tenable [127]. The proliferation of community-managed FPAs in the LMB underscores the need to assess the effectiveness of this fisheries management strategy in relation to clearly defined objectives in order to learn from strengths and weaknesses. While there is no one best set of indicators that is most appropriate for evaluating protected areas across marine and freshwater environments, the basic principle of evaluation is highly transferable from MPAs, with necessary adjustments for the freshwater and community management contexts. FPA objectives can inform the selection of relevant indicators; however, the most useful suite of indicators for a given context may need to be determined through multiple rounds of monitoring and evaluation in order to gage whether an indicator is a true measure of FPA "success." Researchers seeking to provide technical support to communities or organizations for FPA evaluations can now draw on guidelines developed for this purpose [45], and learn from the few but growing examples of published FPA evaluations, e.g., [39]. Interdisciplinary evaluations are a needed addition to FPA management to validate their effectiveness as a tool for protecting freshwater species and habitats, as well as benefiting local people.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4441/12/12/3530/s1, Table S1: List of Indicators and Methods Used for Freshwater and Marine Protected Areas.

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