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Indicators of Coastal Wetlands Restoration Success: A Systematic Review

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Coastal wetlands restoration is an emerging field which aims to recover the ecological characteristics of degraded ecosystems to natural ones. The recent UN declaration of 2021–2030 as the "Decade on Ecosystem Restoration" will hopefully encourage global implementation of these projects. However, a lack of common indicators of restoration success hinders our knowledge on the ecological outcomes of restoration projects. We conducted a literature review to determine trends in monitoring indicators. We classified indicators following the Society for Ecological Restoration template, adapting it to coastal wetlands. We found that indicators on structural diversity (e.g., tree height, fish size) were the mostly commonly used. Indicators on ecosystem function were the second most investigated, with half of the assessed studies including them, especially those focusing on carbon, nutrient and sediment dynamics. We propose a recovery wheel framework adapted to coastal wetlands. Structural diversity indicators are generally easier to measure and often the traits that recover the fastest. However, ecosystem function indicators could be more important to assess the recovery of ecosystem services, which is a primary objective of restoration. Restoration objectives and goals are variable for each project, and we encourage future restoration projects on coastal wetlands to select the most appropriate indicators on the basis of the recovery wheel proposed in this study to plan a monitoring framework. Future studies assessing coastal wetlands restoration ecological outcomes should include ecosystem function indicators and monitor the sites over periods adequate to their recovery.

Keywords: coastal wetlands, restoration, indicator, monitoring, ecosystem functions

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INTRODUCTION

Coastal Wetland Restoration

Coastal wetlands, such as mangrove forests, saltmarshes, and seagrass meadows, are among the most valuable ecosystems in the world. They provide coastal populations with a wide range of ecosystem services such as improving water quality, sustaining coastal fisheries and mitigating floods (de Groot et al., 2012). However, coastal wetlands suffer various anthropogenic threats such as urbanization, reclamation, deforestation, eutrophication, and pollution (Orth et al., 2006; Duke and Maynecke, 2007). These threats have ultimately led to the global cover loss of an estimated 25–50%

of coastal wetlands over the past 50–100 years, making them one of the most endangered ecosystems on the planet (Waycott et al., 2009; Hamilton and Casey, 2016). Mitigation and protection have been the primary efforts to reverse this trend and conserve coastal wetlands and their ecosystem services. Nevertheless, the effectiveness of solely conserving wetlands in Protected Areas or their recognition in international treaties (e.g., RAMSAR) is still debated (Pendleton et al., 2018), partly, because the current degraded conditions might prevent their natural recovery (Perrow and Davy, 2002). Restoration and rehabilitation of natural conditions could play an important strategy for facilitating coastal wetlands recovery (Zedler and Kercher, 2005).

In the past, rehabilitation of an ecosystem had the objective of replacing ecosystem structure or function that has been lost or diminished (Field, 1998), while restoration focused on the return of the ecosystem conditions as close as the "original state" as possible (Jackson, 1995). While both terms have often been used ambiguously, they contrast with approaches such as afforestation or introducing forest in an area where they did not formerly exist in the historical past (Dale et al., 2014; Gann et al., 2019). The Society of Ecological Restoration (SER) was founded in 1988 with the objectives of "advancing the science, practice, and policy of ecological restoration to sustain biodiversity, improve resilience in a changing climate, and re-establish an ecologically healthy relationship between nature and culture" (SER, 2004). According to SER "ecological restoration aims to restore the integrity of ecological systems, therefore restoring a critical range of variability in biodiversity, ecological processes and structures, regional and historical context, and sustainable cultural practices (SER, 2004)".

Over the last 20 years, restoration projects have been increasingly implemented all over the world (Swan et al., 2016; Zhang et al., 2018; Basconi et al., 2020). Restoration science is anticipated to become one of the most important fields within conservation science of the twenty-first century (Hobbs and Harris, 2001). Ecological restoration is considered to be the main strategy to enable the return of ecosystem services (Bullock et al., 2011). While this strategy has been long claimed to be time and money consuming, new methods of ecosystem services valuation suggest that the economic benefits of restoration can outweigh their costs (Barbier et al., 2011; Bullock et al., 2011; Russell and Greening, 2015). The increased attention has led 2021–2030 to be recently declared the "UN Decade on Ecosystem Restoration." [1] However, increasing investment in restoration requires evidence of the effectiveness of the restoration projects (Ntshotsho et al., 2011; Browne et al., 2018).

When evaluating marine restoration success, most published studies on coastal ecosystems use the survival rate of the individuals restored (Bayraktarov et al., 2020b). The success of restoration has been estimated to range between 38 in seagrass and 65% in saltmarsh (Bayraktarov et al., 2016). Considering that marine restoration ranges from US$80,000 to $1,600,000, the projects might not seem cost-effective (Bayraktarov et al., 2016). The chance for success in restoring coastal ecosystems remains uncertain as this discipline is still at an "innovative phase" (Waltham et al., 2020). Organism short-term survival is not the best approach to assess restoration success as it is considered as an indicator of planting method success, and therefore does not assess ecosystem recovery (Wortley et al., 2013). Often metrics are used to measure the biological response of the organism to the restoration intervention rather than to measure a recovery of ecosystem function or services (Hein et al., 2017; Lee et al., 2019). The use of relevant indicators of marine restoration success is essential to produce an accurate estimation of project outcomes (Zhao et al., 2016).

Indicators of Coastal Wetland Restoration Success

Indicators are monitoring metrics that assess ecosystem attributes and can be linked to restoration goals and objectives (SER, 2004; Waltham et al., 2020), and the overall success of the project. A restoration project can reach success if it complies with the terms of agreement (compliance success), or if the ecosystem functions are recovered (functional success) (Kentula, 2000). However, both terms are usually used ambiguously (Zedler, 2007). In the past, indicators have been grouped in three ecosystem attributes including biodiversity (e.g., species richness), vegetation structure (e.g., tree density), and ecological process (e.g., sedimentation rate) (Ruiz-Jaen and Aide, 2005). Ecological processes such as nutrient cycling, carbon dynamics or sediment elevation are important as they provide information on the resilience of ecosystems (Ruiz-Jaen and Aide, 2005). Due to the strong link between processes and services, they are also used to integrate ecosystem services into conservation plans (Egoh et al., 2007). However, ecological restoration aims to facilitate the transition from a degraded ecosystem toward a natural state (SER, 2004). There is therefore the need to provide a target for the outcomes of ecosystem recovery, using reference sites.

A reference ecosystem is a model representing the approximate restoration target (SER, 2004). It is a critical aspect of achieving restoration success as it provides a clear depiction of goals of the restoration project and a development state to evaluate against (Wortley et al., 2013). These reference sites should be environmentally and ecologically similar to the project site, with minor degradation (SER, 2004). In the absence of suitable intact ecosystems in the vicinity of the restored site, it could also be based on historic data about the ecosystem or from modeled outputs (Mcdonald et al., 2016). Functional success of restoration can be ecologically evaluated through comparisons of ecosystem functions indicators in restored with those in reference sites (Zhao et al., 2016).

Recently, the SER created international standards for ecosystem restoration, including a monitoring framework to assess ecosystem recovery (Mcdonald et al., 2016). This recovery wheel propose the assessment of six key ecosystem attributes that restoration practitioners should monitor to evaluate restoration progress and success (Mcdonald et al., 2016). One of these ecosystem attributes is ecosystem functions, described as "the workings of an ecosystem arising from interactions and

[1] Available online at: https://www.decadeonrestoration.org/

relationships between biota and abiotic elements," including ecosystem processes (e.g., primary production, decomposition, nutrient cycling, and transpiration) and properties (e.g., competition and resilience) (Mcdonald et al., 2016). In addition to biodiversity (i.e., species composition), vegetation structure (i.e., structural diversity), and ecological processes (i.e., ecosystem function), they also integrate external exchanges, absence of threat and physical conditions as key ecosystem attributes. However, the use of this recovery wheel should be site specific, and therefore the indicators used to evaluate restoration success should vary depending on the ecosystem studied (Mcdonald et al., 2016). Based on the indicators assessed from the scientific literature, we propose to adapt the wheel to coastal wetlands to improve the relevance of the assessments.

Justification and Objectives

A series of prior reviews focused on assessing outcomes of ecological restoration of terrestrial and freshwater environments (Wortley et al., 2013; Meli et al., 2014; Kollmann et al., 2016). More recently, a literature review on marine coastal ecosystem restoration has been produced with data constrained by the search terms search terms "cost," "feasibility," and or "survival" (Bayraktarov et al., 2020b) which only displays a subset of the available restoration literature. There is a lack of information regarding the monitoring metrics used within the overall scientific community to assess the success of coastal wetlands restoration. In this study, we systematically reviewed the published literature to understand which metrics were used to assess coastal wetlands restoration success, and to elucidate the relation between the restoration of coastal wetlands and the recovery of their ecosystem functions. We specifically answer the following questions: (1) Which aspect of ecosystem recovery do scientific studies investigate when monitoring the outcome of coastal wetlands restoration? (2) Which indicators are used to assess functional success of coastal wetlands restoration? (3) How do these indicators relate to the SER international standards for ecological restoration?

TABLE 1 | List of attributes and sub-attributes classification for coastal wetlands restoration assessment indicators.

Attribute category	Sub-attribute category
Structural diversity A combination of species diversity and diversity of growth forms/strata. This category would also include (if assessed) habitat diversity, spatial mosaics, presence of structural habitat features (e.g., large snags, fallen logs, mangrove roots), trophic levels and functional groups.	Vegetation structure Fauna structure Bacterial structure Algal structure Food web
Ecosystem function The processes of ecosystems, involving interactions between biotic and abiotic elements. This includes process variables as well as raw variables that can be used to provide information on ecosystem function processes such as primary productivity, nutrient cycling, carbon cycling etc.	Primary productivity Secondary productivity Carbon dynamics Nutrient dynamics Sediment dynamics
Species composition The species present in an area and their relative abundance.	Fauna diversity and distribution Vegetation diversity and distribution Bacterial diversity and distribution Algal diversity and distribution
Physical conditions Physical conditions of the restoration site, including hydrological and substrate conditions.	Water physico-chemical variables Soil physico-chemical variables
Absence of threats The presence, absence or measurement of threats to the success of the restoration project.	Pollution Biological threats
External exchanges Linkages and connectivity for hydrology, fire, or other landscape-scale processes; and for habitat for migration and gene flow.	Hydrological connectivity

MATERIALS AND METHODS

A systematic quantitative literature review was performed following the method outlined by Pickering and Byrne (2014). The search was conducted through the databases ISI Web of Knowledge (Core collection; Thomson Reuters, NY, U.S.A.) and Scopus (Elsevier, Atlanta, U.S.A.). These databases were searched through title, abstract and keywords using the research string: (seagrass* OR "sea grass*" OR saltmarsh* OR "salt marsh*" OR mangrove* OR "tidal marsh*" OR "tidal wetland*") AND (restor* OR rehab*) AND (monitor* OR assess* OR evaluat* OR measure* OR success* OR metric*). This research string was build following that created by previous quantitative reviews performed on restoration and coastal wetland ecology (Wortley et al., 2013; Kollmann et al., 2016; O'Connor et al., 2019). Available literature until February 2020 was included.

Eligible papers that monitor either saltmarsh, mangrove or seagrass ecological restoration projects were included by comparing the restored ecosystems to a natural reference site. Secondary sources such as reviews were excluded from the extraction of data because these sources generally do not provide the level of detail required for this analysis (Bayraktarov et al., 2020b). Created or constructed wetlands were also excluded as we focused on studies assessing the potential to restore ecosystem attributes that were once provided by coastal wetlands before their degradation. This study focuses on site specific monitoring; therefore, we did not include regional/national assessments as they often do not include reference sites and merge both natural and artificial restored coastal wetlands. Studies in which restored sites are used for production (e.g., timber production) were not included (Wortley et al., 2013).

The methods and results section of each study was screened to extract the indicators used to assess the ecosystem recovery of coastal wetlands. We extracted indicators monitored in both restored and reference sites. Indicators (e.g., soil organic carbon density) were classified in sub-attributes (e.g., carbon dynamics) following a modified method based on Bayraktarov et al. (2020b). Sub-attributes were nested within broader attributes (e.g., Ecosystem function) (**Table 1**) defined by the International SER (Mcdonald et al., 2016). We did not include socio-economic indicators as this was out of the scope of this review; although we acknowledge that a similar study on their use in assessing restoration success could additionally contribute to this topic. We used the indicators found in the literature to adapt the SER recovery wheel[2] to coastal wetlands.

Additional information on restoration projects was also extracted, such as the time period between restoration activity and monitoring study and the gross domestic product of the country where the restoration occurred as defined by The World Bank (2014). Some studies report a range for the time period between the start of the restoration project and initiation of monitoring (e.g., 7–11 years) so we used the mean (9 years) of the period in the analysis. We also screened for any reference to the SER Primer (SER, 2004) or SER International standards (Mcdonald et al., 2016; Gann et al., 2019) to determine if the project was following these principles.

RESULTS

A total of 67 papers containing 133 restoration site observations were eligible to be reviewed in this study. Papers were spanned over 33 journals, with 12% being published by the journal *Restoration Ecology*. The number of publications increased along the 30 years period covered (1990–2019), with 63% of the papers published in the 2010–2019 decade and a spike in publications in 2019 with 11 papers published (**Supplementary Figure 1**). The papers reported studies from 16 countries (**Figure 1**), 40 of them with high income economies, 13 with upper-middle income economies, 14 with lower-middle economies, and none were from countries with low income economies (**Supplementary Figure 2**). Papers described studies carried on saltmarsh (29), mangroves (28), and seagrass (11). They were all exclusive of other ecosystems, apart for one study which simultaneously investigated the outcomes of saltmarsh and seagrass restoration in Spain (Curado et al., 2012). The period between restoration and monitoring was usually under 5 years (38%), with <15% studies carried out over 15 years.

We recorded the use of 238 indicators, that were classified within 18 sub-attributes nested in six broader attributes (**Supplementary Table 1**). The number of restoration outcome indicators assessed per study varied between 1 and 23, with a third of the studies including five or less indicators. The most common attribute investigated was structural diversity (91%), followed by ecosystem functions (55%), physical conditions (48%), species composition (46%), external exchanges (18%), and absence of threats (6%) (**Figure 2**). The most commonly measured sub-attributes were fauna and vegetation structure which were included in half of the studies each, and around a third of the studies reported on the sub-attributes fauna and vegetation diversity and distribution. The only external exchanges sub-attributes consisted in hydrological connectivity, investigated in 19% of the studies.

Ecosystem functions were classified into five sub-attributes related to ecosystem function, from which the most used were carbon (30%), nutrient (19%), and sediment dynamics (19%), followed by secondary (10%) and primary production (3%) (**Figure 3**). Thirty-two ecosystem function indicators were used to assess the outcomes of coastal wetlands restoration (**Figure 4**). Soil organic carbon density, organic matter, nitrogen density, nutrients and sediment elevation accounted for almost half (47%) of all ecosystem function indicators investigated. Only two studies investigated denitrification, and only one evaluated the greenhouse gas fluxes in restored coastal wetlands. We adapted the SER recovery wheel to coastal wetlands ecosystems, integrating indicators evaluated by scientific literature reviewed in this study (**Figure 5**). This recovery wheel is an example for future monitoring projects in these ecosystems, highlighting the need to adapt the recovery wheel to selected ecosystems. It uses evidence-based monitoring data, derived from coastal wetlands goals and objectives.

DISCUSSION

Coastal wetlands restoration is an emerging field in marine science, with an increased scientific literature investigating its outcomes over the last decade, in particular in 2019. The high number of papers published this year might have been triggered by the 1st March 2019 UN General Assembly declaration of 2021–2020 to become the "Decade of Ecosystem Restoration" (see footnote 1). There is encouraging evidence that scientific literature is increasing its efforts to investigate coastal restoration. However, there is a disparity of studies location with more than half of them being carried out in high-income countries and none in low-income countries. The absence of studies in low-income countries might be due to a lack of reporting, with high-income countries investing more in scientific research. However, countries with highest annual rate of deforestation have low-income economy, mainly in tropical Africa and Asia (Aronson et al., 2010). There is therefore a need to increase partnership between high-income and low-income countries to improve scientific investigation in places where restoration is most needed. Moreover, seagrass restoration assessment studies only accounts for a small proportion of the overall coastal wetlands despite covering a larger area (McKenzie et al., 2020). Finally, while long-term restoration assessment is desired, most monitoring was conducted for less than 10 years. This time period is too short to adequately assess ecosystem functions recovery (O'Connor et al., 2019). For instance, coastal wetlands have been evaluated to recover their carbon dynamics functions at a similar level to reference sites 17 years after their restoration, and mangroves have been estimated to recover

[2]Available online at: http://seraustralasia.com/wheel/index.html

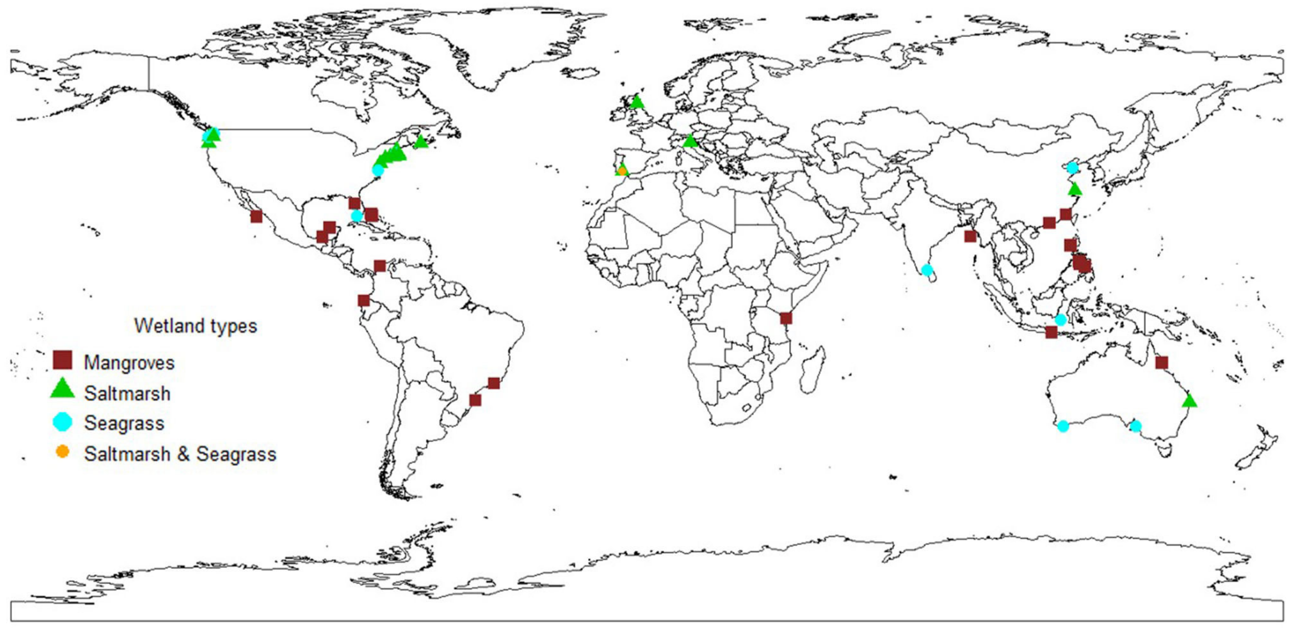

FIGURE 1 | Distribution of coastal wetlands restoration sites from studies reviewed.

their denitrification activity 12 years after restoration (Vovides et al., 2011; O'Connor et al., 2019). Unfortunately, due to a lack of ecosystem function monitoring over long term-period, it is difficult to estimate their recovery time.

The relative success of the restoration projects included in this study is difficult to estimate, mostly due to the wide range of metrics assessed. For instance, we found that more than fifty different indicators have been assessed to estimate the recovery of faunal structure (**Supplementary Table 1**). These indicators were assessing varied part of faunal structure such as nekton density (Bell et al., 1993), crab shell width (Russell et al., 2011), or fish age class distribution (Dibble and Meyerson, 2012). This diversity of indicators makes it difficult to estimate projects' success as the use of one metric over another can result in different outcomes (Basconi et al., 2020). There is a need to provide a common base to assess coastal wetlands restoration projects in order to obtain a clear and comparable success assessment. Gaps in coastal wetlands restoration research are still present, and it is important to resolve them to reach the objectives of the UN Decade on Ecosystem Restoration.

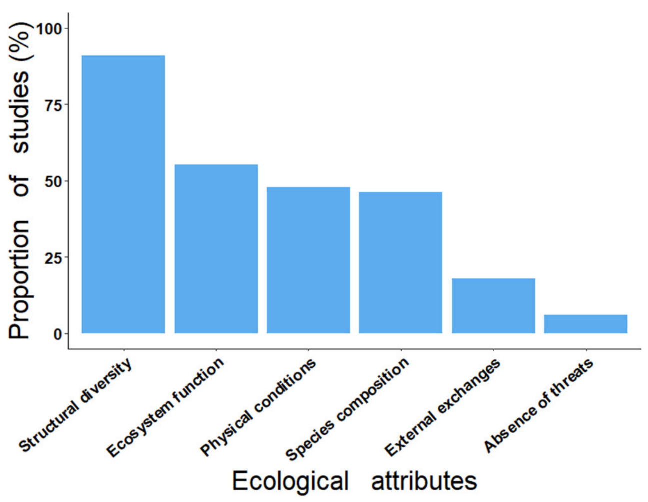

FIGURE 2 | Proportion of the studies investigating ecological attributes.

Ecological Attributes

Previous reviews on restoration outcomes highlighted an increase in measuring indicators of success informing on ecosystem function (Wortley et al., 2013; Kollmann et al., 2016). Our study confirms this trend, with 55% of the studies reporting on ecosystem function indicators. Ecosystem functions of coastal wetlands are being recognized as one of the main targets of restoration by the scientific community. However, most assessment studies are focused on indicators related to structural diversity. This might be because vegetation structure is usually the easiest and cheapest way to determine site condition, compared to ecosystem functions which are slower to recover (Ruiz-Jaen and Aide, 2005; Gibbons and Freudenburger, 2006). Structural diversity indicators are related to the complexity of the ecosystem, from the size of the vegetation to faunal biomass. For instance, Barnuevo et al. (2017) investigated the structural development of mangrove plantations using six structural

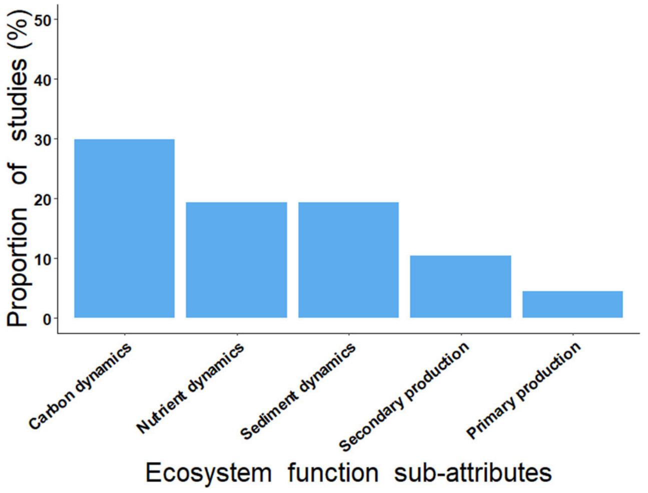

FIGURE 3 | Proportion of studies investigating ecosystem functions sub-attributes.

diversity indicators related to vegetation structure such as tree diameter or density, and Peck et al. (1994) investigated the structural development of restored saltmarsh fauna using six structural diversity indicators such as fauna biomass and density (**Table 1**). While structural diversity is an important attribute to monitor restoration progress, they are not always related to the provision of ecosystem services which is often stated as one of the rationales for undertaking restoration and ecosystem functions (Ntshotsho et al., 2011; Lee et al., 2019). There is therefore a need to improve the assessment of the functional success of coastal wetlands restoration using ecosystem function indicators such as carbon or nutrient dynamics (**Table 1**).

Ecosystem Functions

While coastal wetlands have been understudied for decades, scientific interest has been raised on their ecosystem functions and they are now increasingly studied (Orth et al., 2006; Richir et al., 2020). Coastal wetlands store organic carbon, improve water quality through nitrogen storage and denitrification, and mitigate coastal erosion, and these services have been the center of numerous studies (Alizad et al., 2018; Adame et al., 2019; O'Connor et al., 2019). The increased attention is confirmed by the number of studies investigating the outcomes of carbon, nutrient and sediment dynamics after restoration. Interestingly, carbon dynamics was the most studied ecosystem function, while previous reviews found it to be nutrient dynamics (Wortley et al., 2013; Kollmann et al., 2016). This is certainly due to the recognition of coastal wetlands as being global hotspots of blue carbon (Duarte et al., 2013).

Recent valuations of ecosystem services, linked to ecosystem functions, have potentially been a main driver of the increased scientific interest in coastal wetland restoration (Costanza et al., 1997, 2014; de Groot et al., 2012). Economists have demonstrated that restored, healthy habitats will generate value for both coastal populations and industry (Barbier et al., 2011). Valuation of ecosystem services led to the opening of alternative ways of funding, such as the emergence of carbon markets (Thomas, 2014). This carbon market can be integrated into payment for ecosystem schemes, through a reduction in emissions from deforestation and forest degradation set as international policies (Bullock et al., 2011; Locatelli et al., 2014). Coastal wetlands restoration projects are increasingly using this funding mechanisms, especially in mangroves as they possess the higher potential to store carbon (Wylie et al., 2016). It is therefore essential to understand the outcomes of restoration on the provision of ecosystem services such as carbon storage to facilitate stakeholders' involvement in this kind of projects (Basconi et al., 2020).

We emphasize here the importance of functional success as one of the main objectives of coastal wetlands restoration. Therefore, coastal wetlands restoration projects should include long-term monitoring programs, adapted for the recovery time frame of ecosystem functions. The period of observation is directly related to restoration success (Bell et al., 2014). There is however the need to underpin investment opportunities covering long-term monitoring costs (Waltham et al., 2020). International frameworks and national road maps are required to scale up ecological meaningful projects (Cormier and Elliott, 2017). Additional funding mechanisms such as payment for ecosystem services, biodiversity offset, carbon credits or water quality credit markets could facilitate the access to private capital and unlock major funding to cover the costs (Herr et al., 2015; Waltham et al., 2020). We encourage the use of carbon, nutrient and sediment dynamics success indicators in coastal wetlands restoration monitoring programs. These ecosystem functions are related to regulating services, such as waste treatment, erosion prevention and climate regulation (de Groot et al., 2012). Increased knowledge of project outcomes could facilitate the creation of global market of ecosystem services markets as it would further demonstrate that benefits from ecosystem restoration can outweigh their costs (Bullock et al., 2011).

Monitoring Framework

Among the 67 studies investigating coastal wetlands restoration outcomes, none have used indicators related to all six attributes of ecosystem recovery recommended by SER (Mcdonald et al., 2016). Only five percent of the studies referred to the SER Primer, yet none cited the recent international standards for ecological restoration. This discrepancy can be explained by 25% of the studies pre-dating the SER Primer, and 71% pre-dating the international standards (SER, 2004; Mcdonald et al., 2016). It would be interesting to keep tracking references to SER in the future to see if their principles are followed by the scientific literature. The lack of a common base for monitoring indicators is one of the main concerns associated with a relatively low success rate in restoration of <65% (Egoh et al., 2007; Bayraktarov et al., 2016; Zhao et al., 2016). With the upcoming decade of action, there is an urgent need to determine monitoring metrics and success indicators to assist restoration practitioners

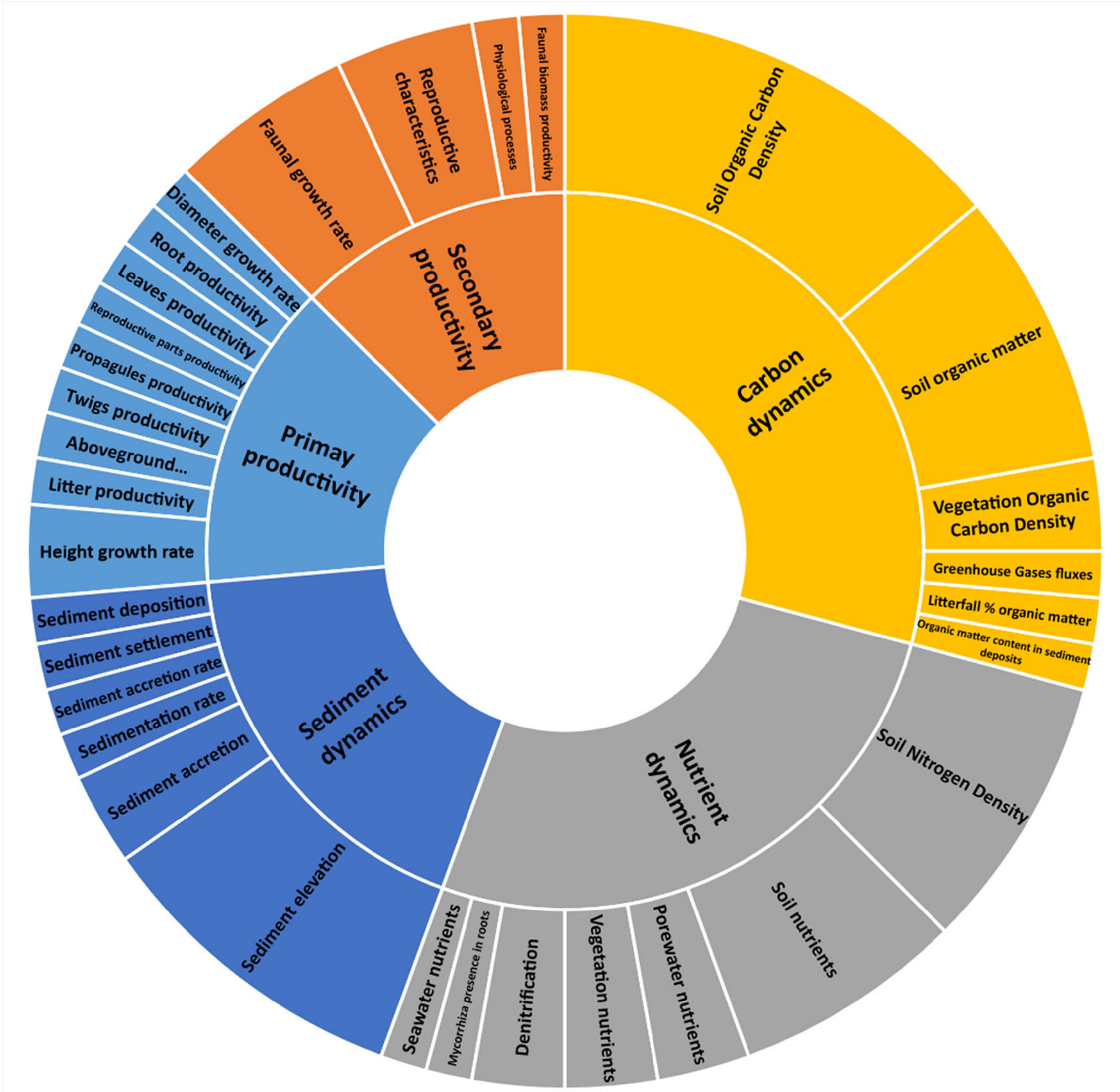

FIGURE 4 | Proportion of indicators (outer ring) nested within their sub-attributes (outer ring) assessed in the scientific literature.

assessing the ecological outcomes of restoration (Waltham et al., 2020). Restoration goals and objectives are dependent on the ecosystem restored (Borja et al., 2010) and the specific circumstances of the restoration sites (Bayraktarov et al., 2020a). The choice of monitoring indicators should be adapted to suit specific restoration sites (Mcdonald et al., 2016). Waltham et al. (2020) pointed out the difficulty to define clear and meaningful measures of success for the enormous range of coastal ecosystems restoration context. SER provided an important contribution to restoration through the creation of a general recovery wheel, but it also emphasizes the necessity to adapt this wheel to specific ecosystem studied (Mcdonald et al., 2016). The recovery wheel built in this study is a first step in the creation of a common monitoring framework for coastal wetlands restoration. We recommend future projects on coastal wetlands to use a recovery wheel based on the sub attributes and indicators presented in this study, and to adapt their monitoring framework to their specific objectives in order to obtain a clear assessment of their restoration outcomes (**Figure 6**).

Caveats

This study reviewed the efforts of the scientific community to assess the ecological outcomes of coastal wetlands restoration. However, most of the ecological meaningful restoration projects are carried by practitioners outside of the scientific field, such as NGOs or foundations, whom do not have the same incentive to publish in the scientific literature (Bayraktarov et al., 2020a). To achieve an overall view of the practice of restoration, we should strengthen the links between practitioners and academics to improve knowledge transmission. One way to do this would be to

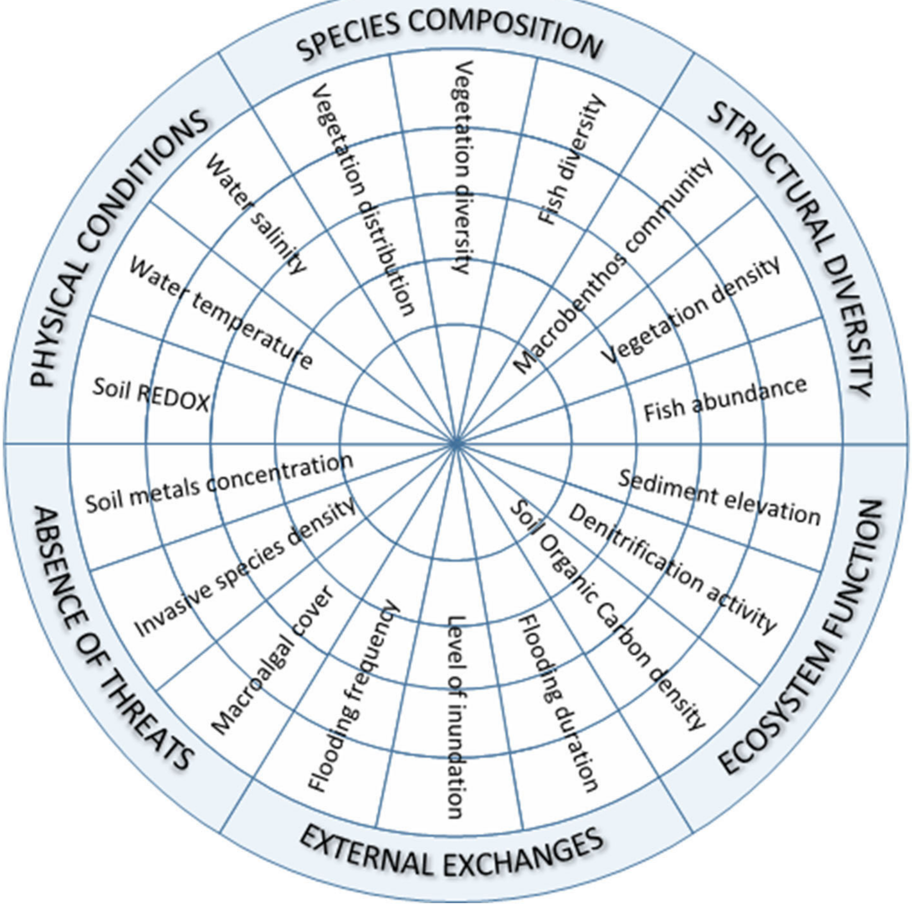

FIGURE 5 | Coastal wetlands recovery wheel including indicators found in the scientific literature.

survey restoration practitioners directly and get information and knowledge which would have been lost otherwise (Bayraktarov et al., 2020a).

We chose to focus on areas where the ecosystem restored previously existed and assessment studies including reference site and related as they aligned better with SER recommendations and therefore provide more meaningful information on coastal wetlands restoration success indicators. However, 90% of the marine restoration literature does not include a reference site; moreover created ecosystems account for a third of wetlands restoration literature (Moreno-mateos et al., 2012; Bayraktarov et al., 2020b). The exclusion of regional and national assessment might have caused the loss of highly relevant restoration data; however, these assessments often lack the monitoring details of site-specific studies required for this review. We also focused our review on English language, with some entries in Spanish, hence we could have missed about 35% of the literature published in different languages (Amano et al., 2016). Because of the limitations on published data globally available, this review is not exhaustive. However, it provides meaningful information on restoration success indicators employed by academics and proposes steps to improve the assessment of ecological outcomes.

CONCLUSION

Restoration ecology is an emerging field in conservation science. However, little is known about the ecological outcomes of restoration and how those have been assessed by measuring specific indicators. The UN Decade on Ecosystem Restoration seems to have encouraged the implementation of restoration projects and there is a need to assess their success. In the past, success was assessed mostly through structural diversity outcomes of restoration, but recent studies demonstrated the importance of measuring metrics related to ecosystem functions as they can be most closely associated with ecosystem services. We emphasize the importance of assessing functional success of coastal wetlands restoration as success indicators, for instance from carbon, nutrient and sediment dynamics assessment. We also recommend the implementation of long-term monitoring programs adapted to the recovery time frame of these ecosystem functions. Further studies on restored coastal wetlands ecosystem functions over long periods are still required to fully understand the outcomes of restoration on ecosystem services. This will facilitate stakeholder investment in coastal wetlands restoration, and the recovery of ecosystem services with economic, social and environmental benefits for all.

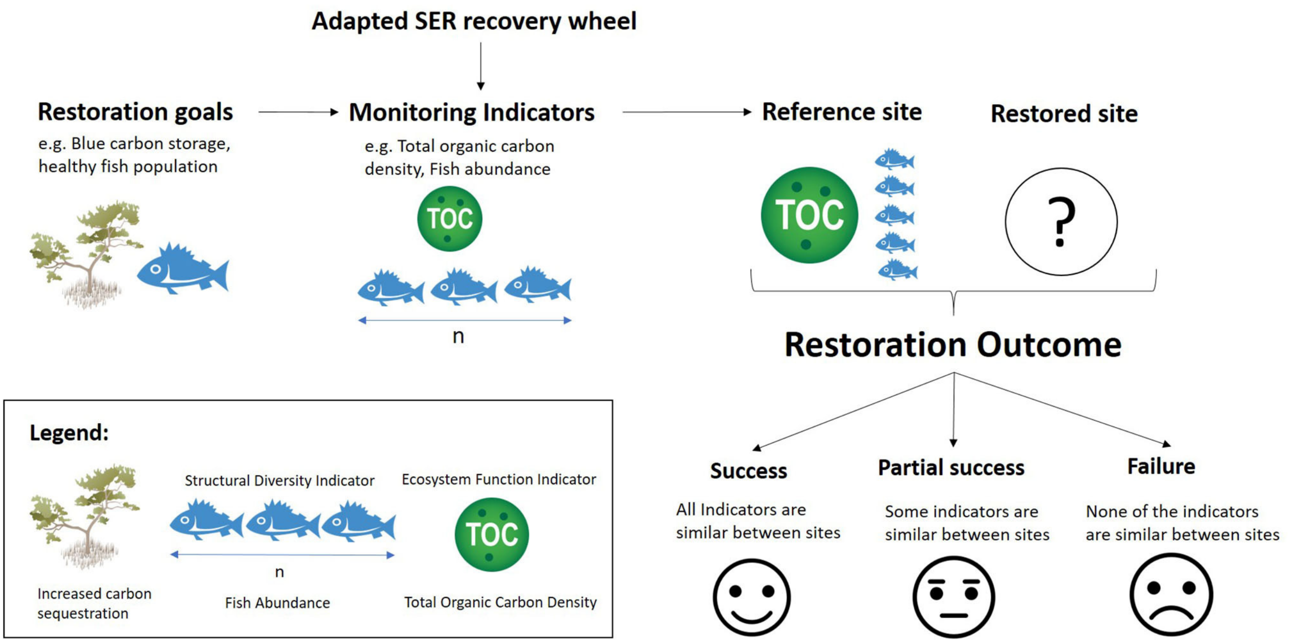

FIGURE 6 | Steps to assess restoration ecological outcome using structural and functional indicators.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Materials**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

CC conceived and developed this review methodology, reviewed and extracted data from literature, prepared the figures and tables, wrote the manuscript. EB contributed to the study conception and development of data extraction methodology and reviewed this manuscript. RP participated in the data analysis and creation of figures and reviewed this manuscript. MA contributed to the development of this review methodology, the creation of figures and reviewed this manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2020.600220/full#supplementary-material

Supplementary Figure 1 | Number of papers assessing ecological outcome of coastal wetlands per year.

Supplementary Figure 2 | Number of papers published per countries economy.

Supplementary Figure 3 | Number of restoration sites per age categories.

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