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Review

Implementing Adaptive Management within a Fisheries Management Context: A Systematic Literature Review Revealing Gaps, Challenges, and Ways Forward

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Abstract: Adaptive management acknowledges uncertainty and complexity in socio–ecological systems, providing a structured approach for learning and for making the needed management adjustments. Despite its utility, there are few examples of how adaptive management has been applied. To identify the extent to which implementation aligns with theory, we conducted a systematic literature review of adaptive management in a fisheries management context to compare how adaptive management was defined, applied and what was deemed important for implementation. Following the PRISMA approach for meta-synthesis, 20 papers were identified and reviewed against the eight key components of adaptive management. Across the case studies, we found ambiguity in the definitions of adaptive management, a varying emphasis on the different components of adaptive management and barriers to adaptive management that stemmed from both outside the process and as part of the iterative cycle. Our analysis suggests that for adaptive management to be implemented in other natural resource management situations, consideration should be given to the active and ongoing participation of those outside management, integrating socio–economic values into decision-making, and ensuring a monitoring plan is implemented. Additionally, attention should be paid to having the time and ability to detect the effects of management actions against a broader background of change. This analysis offers insights into how management support can lead to more effective objective-based decisions, thereby improving management over time.

Keywords: fisheries management; adaptive management; PRISMA; systematic literature review

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1. Introduction

Fisheries management actions have traditionally focused on catch quotas, effort limitations, gear restrictions, size limits, time/area closures, fishing seasons, and license limitations [1,2]. These actions have fallen under a system of track and respond, based on the setting of benchmarks, such as optimal fishing mortality rates and biomass levels, and determining the population status relative to those benchmarks through stock assessment frameworks. However, unexpected fishery collapses have called into question the basic reliability of these approaches [1]. This is due in part to the uncertainties in fisheries management with optimum fishing effort only being known once the sustainable catch is exceeded [3]. To support the objective of an optimum level of fishing effort at a biological and economical sustainable level, the design of a management framework should be able to cope with uncertainty and complexity in the fisheries and the implications of management on the social–ecological system [1,3,4]. Adaptive management has been theorized within fisheries management to address the limitations of fisheries management and to provide a path forward for incorporating uncertainty into decision rules, and ensuring that when assumptions are made, they err on the side of conservation [3,5,6]. In this way, adaptive management is meant to shift away from the traditional 'reactive' approach, towards a structured system for learning from success and failure, and for making the needed adjustments in order to support fisheries' objectives [5,7].

Adaptive management aims to shift management from the traditional command and control strategies to management solutions that account for the complexities and uncertainties in the marine environment and enable decisions to be made in the face of uncertainty [8–10]. As such, adaptive management treats management options as deliberate experiments, with an understanding that there is a limited ability to know or control all of the factors [5,6,9,11]. Adaptive management recognizes that knowledge and understanding of the ecological systems may never be fully known and that policy and management decisions should be made in spite of the unpredictability in the systems and in how these systems will respond to the management actions [3,5,6]. The support for adaptive management has grown considerably in the last few decades, with reference to adaptive management as the recommended approach to addressing the steadily increasing and difficult management scenarios, such as in fisheries' management [12]. Despite being widely promoted, examples of applying adaptive management in practice are few and far between. Previous reviews of adaptive management note the limited implementation of adaptive management across the natural resource management and conservation literature [12–15]. This highlights the need for a closer examination of where adaptive management has been applied to identify lessons to support implementation, as well as the gaps in our understanding of what moves adaptive management from theory to practice.

This paper reviews adaptive management case studies in a fisheries management context for in-depth comparability on how adaptive management has been understood, how it has been applied, and what is important for implementation. It examines the extent to which implementation aligns with theory, providing examples that could be applied to the implementation of adaptive management in a range of other natural resource management scenarios. This paper first provides a background on the development of adaptive management drawn from the published literature within fisheries' management and other natural resource management scenarios. It then expands on the previous reviews [12–15] by undertaking a qualitative meta-synthesis of the fisheries management literature to examine how adaptive management has been implemented to support fisheries management objectives. Based on the review, a synthesis of how fisheries have been adaptively managed is provided. The synthesis considers how adaptive management has been defined, the extent to which the key components of adaptive management (as outlined in [15]) were put into practice, with the key barriers to implementing adaptive management highlighted within the case studies.

2. Development of Adaptive Management

2.1. Conceptualizing Adaptive Management

Adaptive management was initially defined as natural resource management conducted in a manner that purposefully and explicitly aims at increasing knowledge and reducing uncertainty [5,6,15]. Learning to increase knowledge and reduce uncertainty distinguishes adaptive management from conventional management [8,11,16–19]. Adaptive management incorporates learning by combining the need for immediate action with a learning plan that advances understanding of the system, while improving the management outcomes based on that understanding [5,6,10,20–22]. This relationship between learning and decision-making means that management decisions are implemented without fully understanding their outcomes. This feedback between learning and decision-making is a defining feature of adaptive management, resulting in an ongoing iterative process [11]. To inform decision-making and enable feedback to be objective-driven, an adaptive process should be guided by a clarified problem, options to address the problem based on existing knowledge, and identification of key knowledge gaps that may limit understanding of the potential consequences of management actions [5,6,23,24]. The decisions are followed by assessment, with adjustment to the actions as new information about the systems and the impacts of those decisions are observed [8–10]. Adaptive management provides direction to management, whereas the traditional trial and error approach relies on decisions

and choices external to the process to frame the subsequent decisions, hoping that future decisions lead to improved results [17].

How external disturbances may impact a system, the values of various functional responses, system structure, data availability, and how the system may respond to management actions leave room for risks of an undesirable state to occur due to natural or human events [6]. An adaptive management approach involves continuous learning in an effort to reduce uncertainty and risk. Learning has been expressed as a single, double, and triple loop [24–26]. The first loop involves technical learning about the system(s) being managed to correct an undesirable outcome. For example, having established a sustainable stock status, setting a quota for total allowable catch (TAC) that results in an undesirable decrease in the sustainability of a fish stock. The corrective action based on single loop learning would be to lower the TAC quota. The double loop involves institutional and organizational learning of the underlying assumptions, objectives, models, and processes involved in decision-making [19]. In the quota example, double loop learning requires reflecting on how the desirable stock status was set in the first place, updating the models and assumptions used to inform the stock status based on new information. The triple loop refers to learning related to the appropriateness of changing the overall mission and the desired state of the system, which can result in changes in the processes and frameworks of the decision making. For triple loop learning, the quota example requires reflecting on why the focus was on the stock status and not some other desired state. As adaptive management advances over time, the need to revisit and adjust the set-up elements of adaptive management (through double and triple loop learning) can become more pressing [27]. These three learning loops occur at various temporal and spatial scales, with first loop learning occurring more frequently and double and triple loop learning occurring on more infrequent and longer time scales as they evolve in response to the management actions and environmental conditions [10,24,28]. Despite the emphasis on learning, the learning that results through management should be seen as a means to an end—namely, effective management—and not an end in itself [6].

2.2. Approaches to Adaptive Management

Adaptive management theory has developed to encompass a range of approaches that vary in their emphasis on learning [6,10,15,23,27–33]. The initial approach envisioned by Holling [5] and Walters [6] is now labelled as an active approach to adaptive management in which the management approaches and policy decisions are deliberate, large-scale experiments providing opportunities for learning [9]. An active approach focuses on both formalized learning and management as objectives, where the management options are hypotheses to be tested. Through experimentation, an active approach aims to provide data and feedback on the utility of alternative models and policies, rather than focusing on determining a single best option. This approach prioritizes the reduction of uncertainty through learning-focused decision-making that results in effective management [9,23]. The development of adaptive management theory has also led to the inclusion of what is considered to be passive non-experimental approaches [33]. Passive approaches rely on formalized learning as the process underlying the adjustment of management decisions but does not explicitly involve experimentation. The focus is placed on the management objectives with a purpose of generating a resource response by implementing a single course of action that is implemented based on past experiences and the best available modelling and planning, which is then revisited and refined as experience grows [11]. A passive approach applies a formal, rigorous, post facto analysis to secondary data and experiences to frame new choices, understanding, or decisions [17]. In a passive approach, learning is a by-product of decision-making [23]. The degree of available approaches reflects the flexibility in the application to different management problems, noting that there is no one right way to apply the theory in practice.

2.3. Challenges to Adaptive Management

The literature on adaptive management highlights the difficulties of implementation, including ongoing barriers and challenges. Noted challenges include a lack of clarity in the definition and approach; limited success stories upon which to build; management, policy, and funding paradigms that favor reactive rather than proactive approaches; unwillingness to embrace uncertainty; lack of leadership; lack of management resources for the expanded monitoring; failure to recognize the potential for shifting objectives; and failure to acknowledge social sources of uncertainty [8,9,12,15,17]. These challenges reflect barriers that may arise during the process of implementing adaptive management, as well as external factors that can influence management direction. While these challenges could limit the utility of adaptive management to certain scenarios, where management is required, adaptive management can promote flexibility and optimal decision-making, leading to a path forward despite uncertainty [19]. An understanding of the challenges faced and how they were overcome in case studies can support future adaptive approaches to management to move beyond barriers towards successful implementation.

3. Materials and Methods

3.1. Review Structure

A systematic literature review was conducted following the PRISMA approach for a meta-synthesis (Figure 1) [34]. Searching the Scopus and ScienceDirect databases, the following keywords were used to generate the papers for review: ("fisheries management" AND "adaptive management"), ("fisheries" AND "adaptive management"), and ("marine reserve" AND "adaptive management"). These keywords were searched without limitations. Papers were imported into the Covidence program for review, which removed the duplicate papers. The title and/or abstracts of each paper were then screened for relevancy. The papers that included any of the following words in their title and/or abstract were included for relevancy: adaptive capacity; adaptive management; adaptive governance; co-management; adaptive co-management; co-governance; collaborative co-management; collaborative co-governance; community-based management/governance; experimentation in management; fisheries; fisheries management; marine reserve; social–ecological systems; ecological system; structured decision-making; marine reserves; marine protected areas. Papers across all years of publication and geographic location of study were included. To focus the scope on the papers that implemented adaptive management for fisheries management purposes, the papers that addressed any of the following topics were considered not relevant to the present study: bycatch; aquaculture; restoration; wetlands; climate change adaptation (unless specific to fisheries management purposes); ecosystem-based; marine spatial planning; integrated coastal zone management; areas beyond national jurisdiction. Papers published as letters, editorials, commentaries, and PowerPoint presentations, or in a language other than English, were excluded. This review included academic journals, book chapters, reports, grey literature (government and NGO reports), and conference proceedings materials. Duplications missed during the import of papers into the Covidence program were also excluded through manual review.

A full-text assessment of retained papers was conducted by categorizing papers into five categories—mention, theory, suggest, framework, and implement—to identify the extent to which adaptive management was discussed in the paper (Table 1). To scope this review to how adaptive management has been applied, only the papers that fell into the 'framework' and 'implement' categories were included for review, coding, and synthesis purposes. Through the full-text assessment, the additional papers were identified and included in the screening process. A qualitative review was conducted to identify, analyze, and report patterns of themes within the text [35]. Active reading, identifying, extracting, recording, organizing, comparing, relating, mapping, stimulating, and verifying resulted in coding that was examined across the papers. From this approach, the authors identified themes in the literature within the following sections.

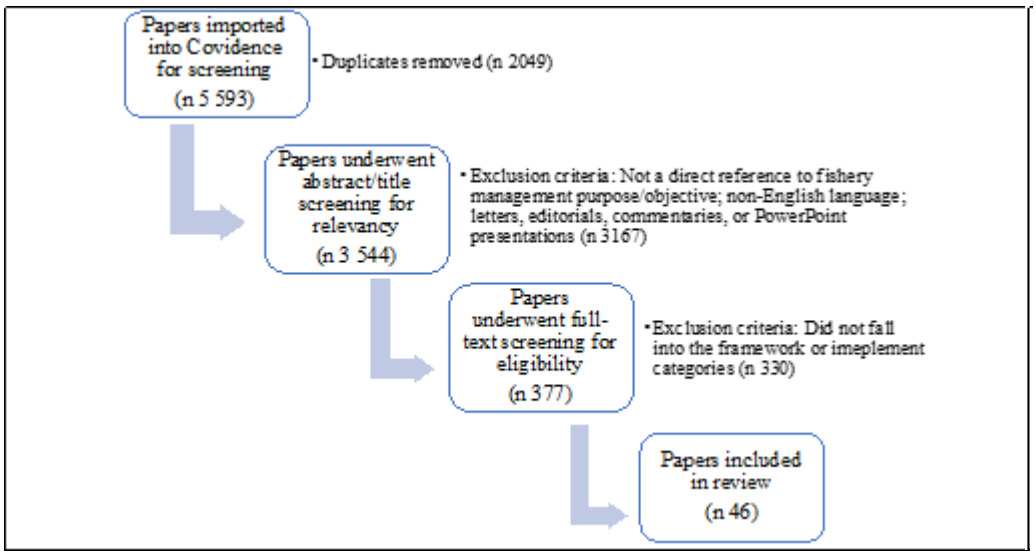

Figure 1. Overview of PRISMA approach taken in paper review.

Table 1. Categories of adaptive management papers reviewed (Adapted from [14]).

Category	Description
Mention	Adaptive management is referenced, however not discussed in detail
Theory	Adaptive management is theorized
Suggest	Adaptive management is identified as an appropriate approach for fisheries management, but a framework or complete analysis of how it is appropriate or could be applied is not provided
Framework	Adaptive management is identified as an appropriate approach and a decision-based framework for how adaptive management may be implemented is outlined
Implement	Adaptive management approach is implemented within a fisheries management context

3.2. How Has Adaptive Management Been Defined?

Papers identified under the 'framework' and 'implement' categories were reviewed to identify whether a clear definition of adaptive management was provided, whether the paper relied on a definition found in earlier literature or if the authors provided their own interpretation of adaptive management. Through this review, any overlap in the concepts used across the papers was examined, as well as any connections between how adaptive management was framed and how it was implemented.

3.3. What Are Key Components of Implementation

The papers placed under the 'implement' category were reviewed to identify which of the key components supported implementation of adaptive management in fisheries management. To guide this review, the eight key components of adaptive management summarized by Rist et al. [15] were examined in each of the papers. The key components reflect the requirements for the application of adaptive management originally noted by [5,6] and are outlined by Rist et al. [15] (pp. 6–7) as follows:

1. Participation of those outside the management institution in order to manage conflict and increase the pool of contributions to potential management solutions;
2. Defining and bounding of the management problem, including the setting of management objectives;
3. Representing existing understanding through system models that include assumptions and predictions as a basis for further learning;

4. Identifying uncertainty and alternate hypotheses based on experience;
5. Implementation of actions/policies to allow continued resource management or production while learning (reducing uncertainty);
6. Monitoring of the effect of implementing new policies;
7. Reflection on, and learning from, monitoring results, comparison with original expectation in order to revise models and/or management actions based on what has been learned;
8. Iterative repetition of this cycle (points 1–6 above) so that management reduces uncertainties and leads to improved management outcomes over time.

The papers were also reviewed for additional components identified by the authors of this paper as being needed to support adaptive management implementation. To assess whether a component was relied on to support implementation, an acknowledged description of an activity having occurred or been planned but not yet completed were used.

3.4. Identified Challenges to Implementation

To identify challenges to implementing adaptive management, the papers under the 'implement' categories were reviewed to identify the challenges or issues that delayed or prevented key components identified above from being implemented. Additionally, the papers under the 'framework' category were also reviewed for barriers identified prior to implementation as needing to be addressed before adaptive management could be implemented.

4. Results

Despite the large amount of early work on adaptive management that focused on fisheries management (see [3,6,36,37]) few papers were found to describe the implementation of adaptive management in fisheries. Of the 46 papers that were deemed eligible for inclusion, 26 were identified under the 'framework' category and 20 papers were identified under the 'implement' category. The 46 papers were distributed across the years of publication, showing an increase in more recent years (Figure 2).

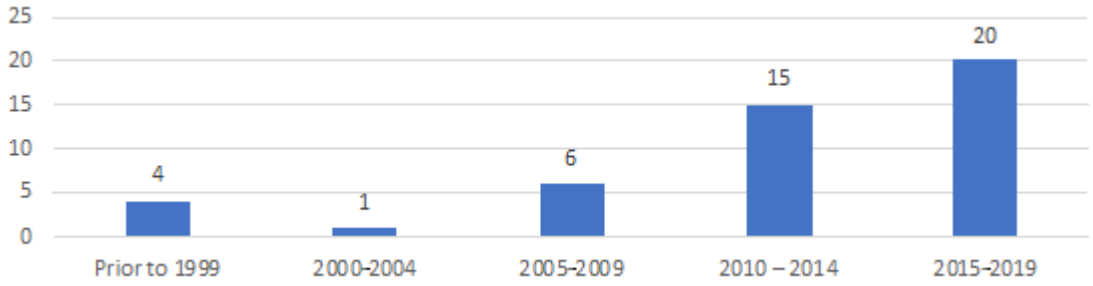

Figure 2. Distribution of included papers ('framework' and 'implement' categories) from prior to 1999 to 2019.

It is likely that some key papers were missed. Similar to Westgate et al. [12], this may be due to papers being mistakenly excluded from the automated search, misinterpretation of some of the content of the papers during manual review, or due to the authors of the papers themselves not identifying their research as adaptive management, despite implementing management experiments. In addition, books and technical reports, which are likely to contain examples of adaptive management in fisheries management, may not have all been included in the databases that were searched.

4.1. Definitions of Adaptive Management

Less than half (21) of the papers included a definition of adaptive management (twelve under the 'framework' category and nine under the 'implement' category). No consistent definition of adaptive management was found across the papers reviewed. Twelve of the

papers paraphrased or cited existing definitions [38–49]. Nine papers provided an original definition of adaptive management [50–58]. Three papers defined adaptive co-management, combining learning by doing and cross-scale collaboration [42,48,50].

Across the definitions, different concepts of adaptive management were emphasized (Table 2). The most common concept identified across definitions was *changing actions in response to new information*. The *iterative and continuous nature of the adaptive management* process was the second highest concept identified across the definitions. Most of the definitions referred to how the process occurred, while four of the definitions provided direction, identifying adaptive management as an *approach to improving management decisions*.

Table 2. Concepts Identified in Adaptive Management Definitions.

Concept in Definition	Number of Papers	Reference
Integrated	2	[40,56]
Multi-disciplinary	1	[40]
Learning by doing	3	[40,42,51]
Systematic process	2	[44,51]
Improving management decisions	4	[39,44,51,52]
Management alternatives as experimental treatments (only)	2	[43,50]
Experimental and experiential	1	[48]
Actions changed in response to new information	10	[39,41,43–45,50,53,54,56,58]
Learning about resources and system being managed	3	[44,53,55]
Iterative/continuous	7	[38,39,45,47,56–58]
Process of trial and error	1	[38]
Response to problems of ignorance and uncertainty	3	[47,49,53]

4.2. Implementation of Adaptive Management

4.2.1. Key Components of Adaptive Management

Each of the 20 papers in the 'implement' category were reviewed to assess whether the key components of adaptive management summarized by Rist et al. [15] were applied. Eleven of the papers discussed more than half of the key components of adaptive management (five components or higher), with only two of the papers discussing all eight of the components of adaptive management. Of the nine papers that discussed four components or less, five of the papers discussed four of the adaptive management components. Overall, most of the papers (nine) discussed four or five of the components.

Across the 20 papers, participation and implementation of a management action/policy were the most discussed components of adaptive management (Table 3). Similarly noted in Rist et al. [15], the papers that discussed participation noted *participation throughout the adaptive management process*, despite it being the first component in the process. Where papers did not discuss participatory processes, the focus was either on a core element of the management process (e.g., modelling approach) or spoke to the institutional players involved in decision-making without reference to the external players. The fifteen papers that discussed the *implementation of a management action/policy* could be due to the scale of the problem. With a focus on fishery resources, management is focused on a specific fishery, as opposed to a broader seascape scale. Another potential rationale for this is that the initial scanning of the papers across the five categories (Table 1) removed those papers that discussed a general framework to be implemented, whereas those in the 'implement' category sought actual implementation leading to a greater likelihood that the implementation steps would be completed. The least common components highlighted in the 'implement' papers were *identification of uncertainty and alternate hypotheses* and *iteration of the management cycle*. The limited number of papers that mentioned uncertainty and alternate hypotheses was likely due to the preliminary data limitations to support management decisions, decisions

to develop a single model to be considered for implementation, and a more passive approach being taken that does not emphasize experimentation. The limited discussion on the iterative nature of the management cycle is likely due to the phase of the management process at the time of publication, where some had not yet undergone a complete cycle.

Table 3. Components of an adaptive management approach included in implementation papers.

Key Components of Adaptive Management	Number of Papers
(1) Participation of those outside the management institution in order to manage conflict and increase the pool of contributions to potential management solutions	15
(2) Defining and bounding of the management problem, including the setting of management objectives	12
(3) Representing existing understanding through system models that include assumptions and predictions as a basis for further learning	12
(4) Identifying uncertainty and alternate hypotheses based on experience	11
(5) Implementation of actions/policies to allow continued resource management or production while learning (reducing uncertainty)	15
(6) Monitoring of the effect of implementing new policies	11
(7) Reflection on, and learning from, monitoring results, comparison with original expectation in order to revise models and/or management actions based on what has been learned	13
(8) Iterative repetition of this cycle (points 1–6 above) so that management reduces uncertainties and leads to improved management outcomes over time	11

Some of the papers further enumerated the components, highlighting the important aspects of specific components. A transparent and unambiguous approach was identified as important for going through the process and to ensure buy-in [59], as was a clear separation of and focus on the specific components of the process [53]. The importance of modelling and analysis, not only to define the management actions to be taken but to estimate the length of time before the results would be apparent was also noted as necessary [47,60]. An emphasis was also placed on the need to include the socio–economic considerations in planning, such that the objectives behind a management approach reflect the values, desires, and preferences of stakeholders [61,62]. Additionally, the papers highlighted the importance of maintaining records of the process, data gathered, actions, and the results to support the ongoing iterative nature of the process [60].

4.2.2. Additional Components Key to Adaptive Management

Fifteen papers included a discussion of the additional components that supported the implementation of adaptive management beyond the eight key components listed above. Legislation and customary law were recognized in four of the papers as being important to the adaptive management process. In each instance, customs or legislation provided the authority to move towards adaptive decision-making [2,38,50,63]. This was coupled with the importance of compliance and the need for institutional capacity to ensure that the rules are enforced. Four of the papers discussed the importance of compliance, some through regulatory or customary means, as being necessary to facilitate the management action/policy [2,39,64,65]. Support through the process, by an 'honest broker' without a vested interest [53], an organization to shepherd through the challenges [64], and leadership in the community [39] were noted as being important to implementation. In the Papua New Guinea case study, the authors noted that a highly decentralized customary marine regime, in which the community leaders have the authority to develop and implement locally appropriate rules and sanctions alongside a strong sense of community, facilitated the adaptive management process [2,39]. In this case, the leadership was well-respected and enabled the enforcement of the closures, which resulted in a high level of compliance. In contrast, in

the Zanzibar case study outlined in Eriksson et al. [65], the authorities were not respected and did not uphold the rules and regulations which resulted in a lack of support and compliance with the decision-making. Additionally, new institutional arrangements, including the distribution of responsibility between government and community or stakeholders was also noted as a key component to implementing adaptive management [38,65].

4.3. Identified Barriers to Adaptive Management

Of the 'implement' papers reviewed, nine of them provided commentary on barriers to implementing adaptive management. Both barriers stemming from outside the adaptive management processes but that impacted the process and those identified as part of the iterative cycle of adaptive management were considered. There was no single barrier that stood out as being the most frequently noted across the papers. In one study that compared two small-scale fisheries, overall poor fisheries management (i.e., unclear rules and regulations, no management plans or objectives, lack of mechanisms to receive and process feedback on the state of the fishery) resulted in the failure for the fishery to take on an adaptive approach [65]. Barriers that impact the planning process include a lack of sustained resources, such as economic and human, which can influence participation in the planning and decision-making, approaches for monitoring, enforcement, and compliance [53,61,65]. A lack of analysis and high levels of uncertainty in modelling and values were also noted to be barriers to planning processes, due to their potential influence on achieving agreement with underlying assumptions, objectives, and potential management actions [60].

Differing perspectives among stakeholders on the values applied in analysis, the underlying objectives, and proposed management actions can lead to disagreements which can disrupt the planning process and remain as an ongoing barrier to iterative cycles of adaptive management [50,53,58,62]. Butler et al. [50] noted that even after a year of implementing a management approach, the fishery stakeholders continued to hold perceptions of seal–fishery interactions that reflected management measures inconsistent with the management plan's principles. The decisions on if, when, and how often the stakeholders should be engaged to reassess the initial data, methodology, goals, and assumptions can influence the continuity and success of the adaptive management process [58].

5. Discussion

The results of the literature search demonstrate similar findings to the previous review studies (see [12–15]). Within the fisheries management literature, less than 5% of the papers found provide an example of the implementation of adaptive management. From the 20 papers that did provide examples of an adaptive management approach, the themes and insights into how adaptive management has been implemented are outlined below.

5.1. The Concept of Adaptive Management Remains Ambiguous

Despite the body of literature that describes adaptive management, there is inconsistency in its definition and interpretation [12,15,28,32]. Holling [5] and Walters [6] conceptualized adaptive management to refer to management actions that purposefully and explicitly decrease ecological uncertainties, through the direct comparison of actions in practice within a fisheries management scenario. With this definition, the components of adaptive management outlined in [15] describe an active approach to adaptive management. Few papers articulated the approach that was taken and, in some cases, where a paper did state the approach being taken, the characterization of the approach did not align with how adaptive management was implemented. For example, papers discussing the management of horseshoe crabs and red knots in Delaware Bay refer to an active adaptive management approach, highlighting the importance of modelling and development of multiple hypotheses to support decision-making [47,53,58,62]. However, the multiple hypotheses were narrowed into one management action; therefore, not tested together as a component of an active approach. Most of the papers demonstrate a passive approach in

which a management approach was adopted (in some cases based on modelling), and is to be updated over time based on new information. Defining adaptive management and describing the approach provides an understanding of the intent and scope of adaptive management. Adaptive management should be precisely defined at the outset to provide guidance on how adaptive management is to be implemented, which can inform a review of the extent to which adaptive management is achieved. Without this understanding, it can be difficult to ascertain what is necessary for adaptive management to be achieved, given the range of approaches that can be taken.

As pointed out by Rist et al. [15], continued confusion of what constitutes adaptive management may be due to the use of the term as a buzzword, without clarity of definition and how it is to be applied. Relying on the core original works, adaptive management links management objectives, learning about the system, and adjusting direction based on what has been learned in reference to the objectives [19]. Compared to trial-and-error processes, which involve learning that is incremental and opportunistic, adaptive management focuses on integrated learning that occurs through intentional decision-making [17,66]. The formalized process of learning that defines adaptive management can then be followed under both passive and active approaches, with the key distinction being experimentation as a step in the process. To support the continued development of the concept of adaptive management and its application in various contexts, clarity on the process being used should be emphasized in papers that report on the application of the adaptive management concept, to support researchers and management practitioners in understanding and distinguishing the approach from other forms of management.

5.2. Implementing Adaptive Management in Customary Fisheries Management

Adaptive management was conceptualized through a westernized lens of fisheries management. However, the concept of adaptive management has expanded to be reflective of customary approaches to fisheries management. Customary management practices demonstrate a passive approach to adaptive management, demonstrating goal setting, predicting outcomes, monitoring, and evaluation of what worked and what failed. For example, the rotational fishery closures to support coral reef management in Papua New Guinea provide an example of adaptive management expressed through a different conceptual framework—placing the taboo, observing the taboo, lifting the taboo/harvesting resources within managed areas, and evaluating the condition of the resource; then, investigating the social, economic, and cultural factors that may influence each phase (Figure 5) [2]. The community leaders managed the fisheries between a low baseline used to signal the placing of a taboo and to cease fishing, and a high baseline to signal the taboo could be lifted and fishing could resume. In these circumstances, reliance was placed on the use of traditional ecological knowledge to inform decision-making without the formalized use of modelling, and community monitoring to examine the social and economic circumstances when making decisions around placing and removing the taboo. The papers that presented case studies of adaptive management highlight the flexibility of such an approach to a range of circumstances.

5.3. Adaptive Management as a Value Driven Process

While the adaptive management process emphasizes data-driven components (modelling, hypothesis development, experimentation, monitoring) the examples of how adaptive management has been implemented demonstrate the influence of the underlying social, economic, and cultural values in informing how the process should move forward, as well as the acceptability of the use of adaptive management. In surveying the fishers about the adaptive management approach taken to address the impacts of seals on the salmon and sea trout stocks, Butler et al. [50] note that the fishers held different perspectives than those of the managers and representatives from the fishing organizations that were involved in the process. As a result, those directly impacted by the decision held different perceptions and understanding of the seal–fishery interactions and on preferred management measures.

Whitney [58] also noted the impact of values on the adaptive management process in Delaware Bay. In this case study, adaptive management experts accounted for uncertainty through statistics, while the wildlife biologists used precaution, which led to disagreements on approach. The rotational fishery closures to support coral reef management in Papua New Guinea also demonstrate the importance of social customs, norms, and values to the process. The social circumstances in these small-scale community scenarios, the ability to limit outsiders from entering the fishery, relatively low human population size, negligible migration, a relatively low dependence on fisheries, and a high degree of occupational multiplicity enabled the community members to switch to other occupations when the restrictions were put in place and were found to have a role in gaining community support for the periodic closures [2,39]. Similar findings were demonstrated by Léopold et al. [61], who noted that efforts were made to align the open periods with the end and the beginning of the year to support the expenses related to the Christmas holidays and school costs. The case studies highlight the importance of considering the values held by those involved in and those impacted by the adaptive management process. To that end, consideration should be given to whose values are being considered, whether there are missing actors, and efforts should be made to integrate said values into the decision-making process.

5.4. Is Adaptive Management Being Successfully Implemented?

Adaptive management is considered to be successfully implemented where: (1) the decision process is iterative and learning oriented; and (2) the process moves management actions towards the intended objectives. The papers reviewed demonstrate that adaptive management does not need to utilize all of the components outlined by Rist et al. [15] for the process to be considered adaptive. The case studies reflect a range of examples which include objective setting, utilization of available knowledge, implementation and monitoring of actions/polices, and the evaluation of outcomes in order to incorporate the new knowledge into future decision-making. Similar to previous reviews (see [13]), the extent to which learning occurs in the adaptive management process was not an explicit focus in the papers reviewed. Eleven of the papers discussed the iterative cycle of adaptive management, with five of the papers providing clarity on how and when learning had been incorporated into the management actions [39,45,59,61,67]. These papers focused on single loop learning in which assumptions, models, and actions are modified. Double or triple loop learning were not discussed, which may be due to the temporal scale for these forms of learning having not yet been reached. Overall, the adaptive management literature lacks clarification on the extent to which learning should occur in order for adaptive management to be considered successful. Where the examples of adaptive management are explored at a point in time, consideration should also be given to the temporal scales of learning and the processes in place that demonstrate future opportunities for double and triple loop learning.

Adaptive management is not meant to be an end in and of itself [19]. The process acknowledges that continuous ongoing adjustments towards more effective decisions will be needed. Even where the objectives are reached, an adaptive process may support maintenance of the objectives as new circumstances arise that may bring change at a larger scale, influencing the system being managed. The papers focused on describing the adaptive management process that was working towards or maintaining a certain level within the system, as opposed to whether the objectives were met. Given the importance of the process, where the evaluation of actions considers why management may not be achieving the intended goals and objectives, to what extent this is at the expense of how the process has unfolded should be part of the reflection that is undertaken.

5.5. Lessons Learned on Implementing Adaptive Management

The review of fisheries management case studies has provided insights into how a developed framework can shift to the implementation of adaptive management. From these cases studies, the following guidance may be transferable to applying adaptive man-

agement in other management scenarios. For this guidance to be transferable, consideration should be given to the differences in goals/objectives of management, the actors involved, the governance systems in place, and the feasible management actions that could be applied. For example, the application of adaptive management in marine protected areas (MPAs), may be more complex where an MPA has ecosystem-level or multi-species/habitat objectives, a wider array of actors involved, and involves the management of more than one human activity through various legislative, regulatory, policy, or conventional means. These considerations add layers of complexity that may not be found in fisheries management but will influence the feasibility of implementing adaptive management.

5.5.1. Active and Ongoing Stakeholder Participation

The frequency with which participation was discussed in the papers reviewed demonstrates the importance of active and ongoing participation throughout the adaptive management process [5,6,17,23,33,68]. Participation allows for the biological, economic, social, political and cultural values and perspectives held by those involved in the process to inform objective setting [69]. Where objectives shift, due to changes in perspectives and circumstances, participation throughout adaptive management enables the process to continue to reflect the values of the time and reprioritize the objectives as needed. The case studies demonstrate that enabling participation and ensuring that the right people are involved can reinforce adaptive management approaches through the reinforcement of relationships, support of social cohesion, and compliance with management, while also enabling the integration of various knowledge forms into decision-making and providing additional information on the social, economic, cultural, and political considerations [39,50,58]. Adaptive management processes should include continued decisions on if, when, and how often participation occurs.

5.5.2. Socio–Economic Implications of Management Actions Should Be Integrated into Decision-Making

Consideration of the socio–economic implications throughout the process enables an understanding of the social–ecological system in which the decisions are being made and the potential impacts of the management decisions when assessing options. Differing perspectives on the values applied in analysis, underlying objectives, and proposed management actions can lead to disagreements and disruptions to the planning process. However, the inclusion of values, desires, and preferences of stakeholders can support the legitimacy of the management decisions, ground decisions within the community, and lead to greater compliance with the management actions when implemented [39,58,61,62].

5.5.3. Monitoring Is Necessary for Adaptive Management to Be Iterative

Adaptive management is dependent on well-designed monitoring programs that are implemented and maintained to detect changes resulting from management actions [12,70,71]. The papers reviewed highlight an emphasis on the initial data collection to inform an initial understanding of the social–ecological system and management problem (i.e., the nature of the fishery, including geographic location and depth, fisheries actions previously taken, scale of problem). An assumption made by the authors was that all of the papers would discuss monitoring, given its central role in informing learning. However, only eleven of the papers provided commentary on monitoring. This may have been due to papers being focused on certain aspects of adaptive management, having not yet reached the monitoring stage following implementation of actions, and, in some instances, monitoring was mentioned as part of the process but not discussed in detail [39,47,58,62,65,72].

5.5.4. Adaptive Management Requires Time

Adaptive management is no easy feat. This is evident by the limited number of papers that were available for review. Adaptive management's potential contribution depends on the time required to learn and the ability to detect the effects of management against

broader changes within the social–ecological system. The reviewed papers and the general literature highlight the ongoing need for resources (human, financial, technological, etc.) and support for the process, as well as appropriate time scales for monitoring outcomes to be realized and for learning to occur. These place difficult demands on management systems [12,17]. At the outset, identifying the likely resource needs, establishing a support system, and communicating the realities of adaptive management to stakeholders and political leaders, are needed for adaptive management to be fully implemented. In addition, identification of the challenges should occur throughout the process to enable solutions to be developed and the process to continue.

6. Conclusions

Adaptive management can provide a defensible trade-off between precaution and resource use, shifting away from the traditional 'reactive' approach, towards a structured system for learning from success and failure, and for making needed adjustments in order to support fisheries objectives [5,7]. However, similar to previous studies (see [12]), this review notes that, despite the high volume of literature on adaptive management, there are few examples of adaptive management being implemented. Adaptive management is hailed as a panacea to management problems; however, it remains challenging to implement, with an apparent underestimation of what adaptive management entails, the feasibility of the circumstances, and what efforts are necessary for its implementation. The papers also highlight the time required to implement and learn from the process, acknowledging the difficulty in detecting the effects of management over the long-term, while being influenced by the change occurring at larger spatial and longer temporal scales. Without acknowledging these elements when recommending adaptive management, the result will be a continued lack of implementation of adaptive management.

As a process that requires support and participation for implementation, future research on adaptive management should examine how participation occurs, the influence of the actors in the process, how feedback and input are incorporated into the process, and how this is evaluated and considered in the evolution of the adaptive management process. Additionally, in the case studies of where adaptive management was implemented, further exploration to understand the extent to which learning across the three loops has occurred and been integrated back into the adaptive management process would further the understanding of how adaptive management is applied on an iterative basis. Ongoing research into the application of adaptive management will enhance the guidance needed to move adaptive management from theory into practice.

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