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A systematic review of participatory integrated assessment at the catchment scale: Lessons learned from practice

Grace B. Villamor[a,b,*], Lisa Sharma-Wallace[c], Meine van Noordwijk[d,e], Tim Barnard[a], Dean F. Meason[a]

[a] Scion (New Zealand Forest Research Institute), Private Bag 3020, Rotorua 3046, New Zealand
[b] Center for Development Research, University of Bonn, Germany
[c] Independent Researcher, Reno, United States
[d] World Agroforestry (ICRAF), Bogor, Indonesia
[e] Plant Production Systems, Wageningen University and Research (WUR), Wageningen, the Netherlands

A R T I C L E I N F O

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A B S T R A C T

Participatory integrated assessment (PIA) emerged as a response to conventional integrated assessment methods in the mid-to-late 1990s. PIA is based on the tenet that more inclusive stakeholder involvement may lead to increased accountability and legitimacy in decision-making, greater levels of trust and social learning between participants, and improved quality and relevancy of knowledge outputs. In this paper, we conduct a systematic literature review to update and deepen our understanding of the approaches, methods, opportunities, and challenges associated with PIA as applied at the catchment scale. Of the total 278 studies identified in our literature search, only 37 catchment-level cases presented a clear PIA application. From our review, lessons learnt were drawn in relation to the integration of less-easily quantified areas of social science, entry and exit planning in PIA, boundary work on issue cycles and accounting for the human dimension. We conclude that PIA is a potentially useful approach for navigating the dual social-ecological dimensions of current environmental and resource management issues, especially when projects include tailored objectives and methods, user-friendly outputs, and early and consistent stakeholder involvement. However, we also highlight gaps in the field concerning the integrative reach of PIA, PIA's real-world impact, and the relationship between PIA processes and outcomes along stages of environmental issue cycles. We conclude that further work is therefore still needed to help advance the field of PIA in both research and boundary work practice.

1. Introduction

Methods for natural resource management at the catchment scale have historically been too disparate, as public decision-making on issues of current interest tends to engage with one area or problem at a time at the expense of a more holistic approach (Jakeman et al., 2007; Jakeman and Letcher, 2003). Traditional environmental management paradigms have often involved the top-down application of technocratic tools to achieve linear and well-defined ecological goals (Brunner et al., 2005; Pahl-Wostl, 2007). However, the increasing complexity, or increasingly obvious complexity, of today's "wicked" environmental problems necessitates a broader purview in which socio-ecological interconnections are acknowledged and addressed in order to realise truly robust solutions (Brunner et al., 2005; Folke et al., 2005; Pahl-Wostl, 2009). The field of integrated assessment (IA) thus began to gain prominence in the 1980s and 1990s as a means to circumvent the traditional approach (Rotmans and van Asselt, 1996; Toth and Hizsnyik, 1998). Defined most accurately as a process rather than a discipline in itself, IA's aim is not to produce new scientific knowledge. Instead, the field attempts to combine knowledge about a specific problem from different disciplines in order to directly inform policy- and decision-making activities (Jakeman and Letcher, 2003; Rotmans, 1998). In this sense, IA is a specific form of boundary work that aims to link knowledge with action (Cash et al., 2003; Clark et al., 2016) and that can benefit from understanding the way public issue attention cycles require: A) a shared understanding of what is at stake, B) a common commitment to

* Corresponding author at: Scion (New Zealand Forestry Research Institute), Titokorangi Drive (formerly Longmile Rd), Private Bag 3020, Rotorua 3046, New Zealand.

E-mail address: Grace.Villamor@scionresearch.com (G.B. Villamor).

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(ambitious) goals to deal with it, C) an operationalisation that is perceived to be both efficient and fair; and D) a monitoring and evaluation system that is open to innovation rather than enforcing compliance with rules as formulated (Tomich et al., 2004; van Noordwijk, 2019). Depending on the stage of current issues of focal interest, IA may seek progress in the partly simultaneous processes A through D.

Though the disciplines being integrated in IA should ostensibly include a wide range of research areas, including social science, economics, the biophysical sciences, and perspectives from local stakeholders (Jakeman et al., 2007), early iterations of IA emphasised the use of quantitative modelling tools that drew their primary inputs from the natural science (or quantitative social science) disciplines (Kloprogge and van der Sluijs, 2006; Parson, 1995; Ridder and Pahl-Wostl, 2005; Rotmans, 1998). Such an approach was unable to sufficiently account for the qualitative and human considerations that nevertheless assert a significant influence on the causes and impacts of complex environmental problems (Pahl-Wostl, 2005). In the worst case, critics argued that IA's limited focus potentially decreased both the usefulness and usability of the field (Rothman and Robinson, 1997; Scherhaufer, 2014). The rise of debates around the nature of science and its relationship with society, coupled with a growing acknowledgement of social-ecological uncertainties, ultimately resulted in a shift in the field from the search for “right” answers toward “robust” answers that incorporate a range of perspectives and knowledge forms (Salter et al., 2010). Participatory integrated assessment (PIA) subsequently emerged as a response to more conventional IA processes in the mid-to-late 1990s, based on the tenet that more inclusive stakeholder involvement may lead to increased accountability and legitimacy in decision-making processes, greater levels of trust and social learning between participants, and improved quality and relevancy of knowledge outputs (Kloprogge and van der Sluijs, 2006; Salter et al., 2010; van Asselt et al., 2001; van Asselt and Rijkens-Klomp, 2002).

Both recent and earlier reviews of PIA paint a picture of a still-emerging field (Kloprogge and van der Sluijs, 2006; Salter et al., 2010; Scherhaufer, 2021; van Asselt and Rijkens-Klomp, 2002), with several studies adopting an exploratory or research focus with the aim of improving future PIA processes and outputs. Salter et al.'s (2010) review notes that early assessments were more commonly situated in local, regional, and national contexts than the traditional larger-scale IA analyses applied to issues such as the potential impacts of global climate change (see Rotmans and Dowlatabadi, 1998; Weyant et al., 1996), though climate change remains a prominent focus. The authors also find that the most common PIA tools and methods include modelling and/or qualitative and mixed qualitative/quantitative scenario approaches, most often facilitated through stakeholder workshops and focus groups. They concur with Kloprogge and van der Sluijs (2006) that there is limited evidence of PIA policy impact and only anecdotal confirmation of social learning, perhaps highlighting the need for more comprehensive formal evaluation mechanisms. Other areas flagged as critical for future study include the tension inherent in combining qualitative and quantitative approaches and its attendant questions surrounding the translation of qualitative and “human” dimensions for use in quantitative tools, even given greater stakeholder representation. Increased representation garners its own set of issues around which stakeholders get to participate and to what extent, alongside the potential impact of pre-existing power differentials. Finally, and critically, questions remain regarding the relationship between PIA and current institutional structures. PIA is simultaneously dependent on and hindered by institutions, relying on the research funding they provide but not always aligned with traditional measures of success and/or academic productivity. In trying to synthesise lessons learnt, it is important that both the ecological (what issue is at stake, and where?) and social (how far apart are stakeholders in knowledge, interpretation, and underlying value systems?) dimensions of PIA applications are understood and taken into account.

Van Asselt and Rijkens-Klomp (2002), Kloprogge and van der Sluijs (2006), and Salter et al.'s (2010) reviews provide a crucial snapshot of the field in its early days; more than ten years later, we propose an updated analysis of PIA applications and tools that follows Salter et al.'s (2010) call for a more comprehensive examination of participatory methods and lessons learned from the implementation of PIA in practice. In the following sections of the paper, we present and discuss the results of a systematic literature review exploring the application of PIA at the catchment scale. We outline our literature review methodology before summarising results from the review in the areas of PIA approaches, methods, and outcomes. The final section of the paper reflects on key themes and lessons learned from practice, including a discussion of ways in which PIA has - and has not - evolved in response to initial critiques.

2. Methods

To update our understanding of the existing body of PIA literature, we chose to follow the systematic review methodology, a structured mode of literature review that is gaining popularity across both the natural and social sciences (Jones, 2004; Petticrew and Roberts, 2006).

2.1. Search scope and criteria

Our original search focus for the systematic literature review concerned the relationships between water flows and planted forest areas, based on the growing perception that trees require so much water. However, confirming the fact that more research is needed on the relationship between forests and water flows, an initial literature scope revealed key topical gaps on the subject of PIA and forest-water interactions. A scoping search on IA in the area of forests and water returned only a small number of results that moreover lacked a participatory or collaborative focus. Separate searches on PIA and forests and PIA and water returned a higher number of results, but most results were focused on only forests or only water, thus bypassing their potential relational links. In light of these gaps, and in order to nevertheless capture the dynamic “flows” between water and trees or other natural features, we ultimately broadened our final search focus to encompass PIA at the catchment scale.

In line with IA's strong problem- and user-oriented approach, we limited our search criteria to case study results that included a description of a corresponding problem- or use-outcome. While most empirical search results describe the development and application of IA at a specific case study site, we searched for publications that further indicated a specific management outcome, such as stakeholder interest or use of the IA beyond the initial research project, in order to glean at least some sense of future IA adoption or uptake by managers and practitioners. Our full set of inclusion and exclusion criteria used for literature search and refinement is summarised in Table 1.

Table 1
Inclusion and exclusion criteria used for literature search and refinement.

Inclusion criteria	Exclusion criteria
Integrated assessment conducted or completed	Integrated assessment not conducted or completed
Participatory or collaborative focus	Lack of participatory or collaborative focus
Case setting: basin, catchment, or watershed area	Case setting: other than basin, catchment, or watershed area
Empirical study	Conceptual, theoretical, or review focus
Participatory methods described	Participatory methods not described
Outcome of integrated assessment described	Outcome of integrated assessment not described
Type of study: article, book, book chapter, working paper, report, conference paper, or thesis	Type of study: not article, book, book chapter, working paper, report, conference paper, or thesis
English language publication	Non-English language publication

Table 2
Literature search and filtering results.

Phase	Description	Results
	Total studies	278
	● ScienceDirect	● 56
	● Scopus	● 181
	● SpringerLink[a]	● 10
	● Google Scholar	● 22
Phase 1: Initial literature search	● Google Web	● 9
	Total studies	278
	● Total included	● 194
Phase 2: Elimination of duplicates	● Total excluded	● 84
	Total included	94
	Total excluded[b]	100
	● Integrated assessment not conducted or completed	● 17
	● Lack of participatory or collaborative focus	● 53
	● Conceptual, theoretical, or review focus	● 23
	● Case setting: other than basin, catchment, or watershed area	● 3
	● Non-English language publication	● 2
Phase 3: Title, abstract, and keyword screening	● Other[c]	● 2
	Total included	33
	Total excluded	61
	● Integrated assessment not conducted or completed	● 20
	● Lack of participatory or collaborative focus	● 9
	● Conceptual, theoretical, or review focus	● 3
	● Case setting: other than basin, catchment, or watershed area	● 5
	● Participatory methods not described	● 8
	● Outcome of integrated assessment not described	● 13
Phase 4: Full-text screening	● Other	● 3
Phase 5: Case extraction	Total unique cases	37

[a] SpringerLink, Google Scholar, and Google Web only allowed title and/or full-text searches at the time of our literature search. Full-text searches returned an unmanageable number of results for manual screening, so we performed title searches, scanned the abstracts and keywords of each result, and included all relevant studies in our Phase 1 body of literature. This "pre-scanning" method explains the lower number of results noted for SpringerLink, Google Scholar, and Google Web.
[b] Some publications met more than one exclusion criterion, but we noted only one criteria for each study.
[c] "Other" includes edited books results (individual chapters screened and extracted for inclusion in the next phase), studies with questionable publisher quality, and studies that were not available within the project time constraints.

2.2. Literature search and filtering

We performed our initial literature search using the search string ("integrated assessment" OR "integrated modelling") AND ("participatory" OR "collaborative" OR "stakeholder") AND ("catchment" OR "basin" OR "watershed") in the ScienceDirect, Scopus, SpringerLink, Google Scholar, and Google Web databases. Search methods varied slightly depending on the database; for example, wildcard searches are permitted in some databases and not others, and some databases permit title, abstract, and keyword searches while others only allow title and/or full-text searches. We documented the specific details of each search and eliminated duplicate results before applying our previously-selected filtering criteria to the results. Results were filtered on the title, abstract, and keyword level followed by the full-text level, for a final total of 33 publications and 37 individual case studies.[1] We summarise our literature search and filtering results in Table 2.

2.3. Data extraction and organisation

We extracted and organised the data from the final body of literature based on a series of data categories selected for their alignment with our research focus and questions (Table 3). Following our focus on PIA's practical implications, we were particularly interested in the IA process and outcome, including the chosen IA approach and specific methods for implementation. We further viewed positive (enabling) and negative (constraining) factors as critical variables that provided essential context to the ultimate outcome of the IA process.

2.4. Data analysis and synthesis

We based manual coding and analysis activities on the categories outlined in our data extraction and organisation template. We used the template to compare and contrast categories across studies, noting crucial differences and similarities in context, approach, and methods and their stated or implied influence on PIA outcomes. The structured mode of data extraction and organisation required by the systematic review allowed us to flag not only emerging themes and patterns in the data across cases, but also those areas where data was lacking or missing altogether.

The remainder of the paper presents the results of the systematic literature review. We begin by summarising the PIA processes and outcomes highlighted in the literature before discussing the implications gleaned from the case studies for PIA in practice, including challenges, opportunities, and lessons learned.

3. Results

After screening studies for relevance, our final body of literature included 33 publications and 37 unique cases that apply PIA at the catchment scale. Fig. 1 reveals a slow but steadily increasing trend of studies published between 1997 and 2020. Given IA's strong basis in climate change research (see Morgan and Dowlatabadi, 1996; Rotmans and van Asselt, 1999; Weyant et al., 1996), and in light of increasingly obvious climate impacts and resonance across world regions, the case

[1] Some publications covered the same case study, while others included more than one case study. We combined and extracted case study results as needed for a final individual case study count.

Table 3
Data variables used for data extraction and organisation.

Category	Components
Bibliographic details	Author, title, and publication information
	● Research question(s)
	● Definition of IA
	● Study findings
Study context	● Study limitations as described by author(s)
	● Location
	● Timeframe
	● Sector
	● Community description
	● Issue or problem
Case context	● Actors involved
	● Desired outcome
	● Actual outcome
	● Design/approach
	● Methods
	● Methods of outcome measurement
IA process and outcome	● Policy impact
	● Positive (enabling) variables
Reasons for outcome	● Negative (constraining) variables
	● Gaps identified by researcher
	● Researcher comments
	● Relevance to Forest Flows
Other	● Overall context

study canon will likely continue to grow. The cases are geographically distributed across Africa (6 cases), Asia (3 cases), Australia/Oceania (6 cases), Europe (13 cases), and North America (9 cases), with clear room for more growth in Africa, Asia, and South America (Fig. 2).

All cases include a prominent water component, in line with our search parameters specifying search results at the catchment scale. The specific geographical scale of the cases varies, however, ranging from a 23 km^2 coastal lake catchment to a 1.8 million km^2 transboundary watershed area. Agriculture features prominently in the cases, both as a source of water contamination and/or a potential point of conflict with other land-uses around water use and supply (e.g., Allain et al., 2020; Carmona et al., 2013a, 2013b; Nguyen-Khoa et al., 2005; Parker et al., 2014; Reinhardt et al., 2018; Vogl et al., 2017). Authors note a variety of other land-uses in study areas, including forestry, recreation, and tourism, but these are generally included for context and not explored in depth. The primary issues of concern in the cases include water quality and quantity problems (17 of 37 combined cases), climate and global change impacts (8 of 37 cases), and more general integrated water resources management encompassing economic, environmental, and social concerns (12 of 37 cases) (Fig. 3).

In terms of research objectives, the case results overwhelmingly reflect PIA's traditional problem-orientated focus. While some projects additionally incorporate an explicit scientific or research purpose (e.g., Allain et al., 2020; Barthel et al., 2016; Caille et al., 2007; Reinhardt et al., 2018), all cases aim to employ PIA to aid policy- and decision-making processes in real-world management situations. This stands in contrast with earlier reviews that found that the bulk of PIA studies adopted an exploratory focus to aid further development of the field (Kloprogge and van der Sluijs, 2006; Salter et al., 2010), but is an unsurprising outcome given that PIA is now much more firmly established as a methodological tool.

3.1. Methods and approach

3.1.1. Modelling and simulation

We now turn to a more detailed treatment of PIA in the cases, providing an overview of specific approaches, methods, and outcomes. Salter et al.'s (2010) review highlights policy exercises, scenario analysis, and computer models as the most common approach or design in PIA, with modelling occupying a primary role due to the ability to systemise and synthesise large quantities of quantitative knowledge across disciplines. Van der Sluijs (2001) reminds their readers that modelling is only one of many tools that may be adopted for PIA; our results nevertheless confirm that quantitative integrated assessment modelling (IAM) remains the primary approach for the assessment process, with all but 3 of 37 cases incorporating a modelling element, often agent-based in form. Most of the PIAs (30 of 37 cases) draw on pre-existing models or modelling platforms with more or less adaptation of the model or platform according to the context. Reflecting the geographical (catchment) target of the review, the modelling suite invariably includes a hydrology element or sub-model. Disciplinary "integration" takes place through the inclusion of other components or sub-models representing farming practices, landscape, climate, economics, population growth, habitat, biodiversity nutrient loads, pollutant concentration, energy use, management/governance regimes, or, most commonly, a combination of these elements (generally numbering from three to five) based on the case context. In addition to or instead of quantitative modelling, 18 of 37 cases incorporate soft modelling techniques ranging from concept maps to participatory mapping to Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis.

Following Salter et al.'s (2010) categorisation of modelling approaches in PIA, the majority of the assessments adopt a participatory modelling methodology, thus allowing for direct use of models by participants. In participatory modelling, models are constructed with to

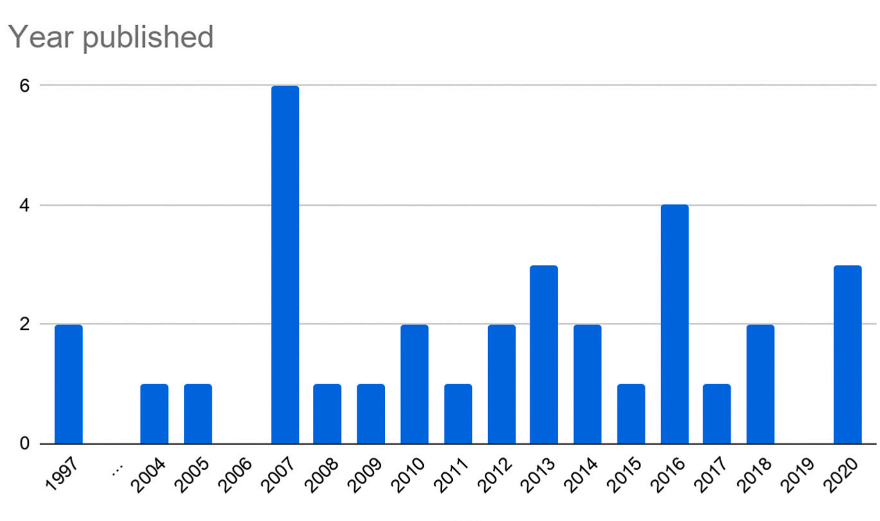

Fig. 1. Distribution of studies by publication year.

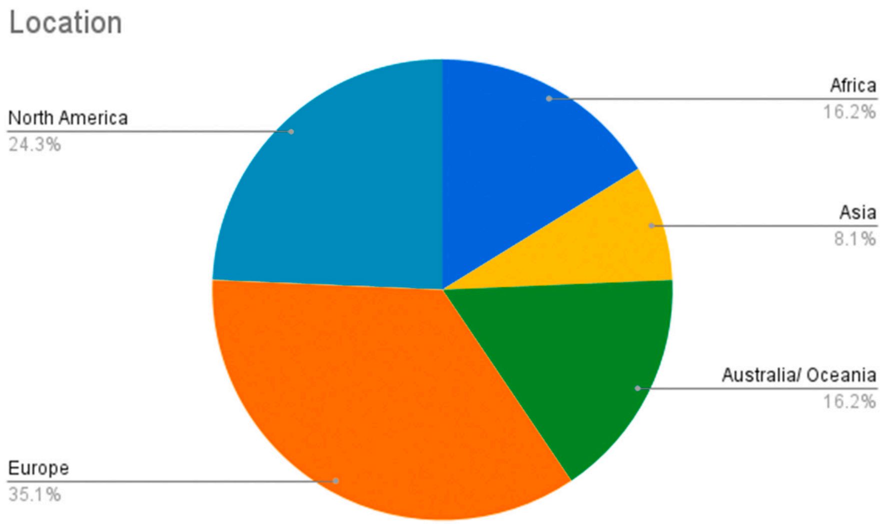

Fig. 2. Distribution of cases by location.

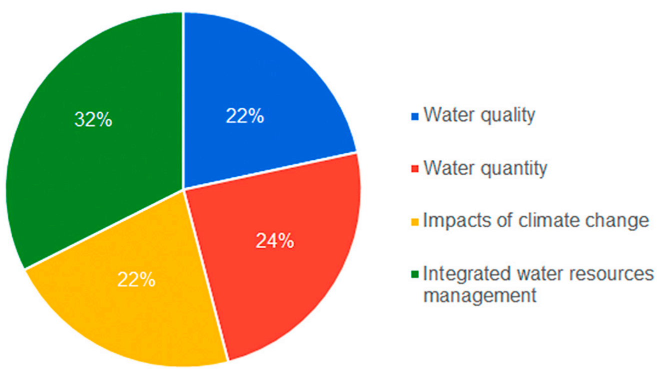

Fig. 3. Distribution of cases by primary issue.

update and deepen our understanding of the approaches, methods, opportunities, and challenges associated with PIA as applied at the catchment scale first-hand and iterative input from participants regarding system representation, assumptions, indicators, and criteria. Salter et al. (2010) also describe indirect modelling, in which outputs which have already been developed are presented to participants for feedback and discussion, though a much smaller number of studies in the review utilise this approach (e.g., Dymond et al., 2010; Malve et al., 2016). Participation in the cases is primarily facilitated through a series of stakeholder workshops in which participants define and conceptualise the problem or issue; identify endpoints, criteria, and indicators; offer feedback and critique for model improvement; and test the model by implementing a suite of different management interventions. The PIAs incorporated at least one stakeholder workshop, up to a maximum of eight workshops, in 33 of 37 cases. Other participatory methods include interviews, site visits, and open meetings, with PIA information and results disseminated through mediums such as websites, newsletters, and local presentations.

Contrary to Salter et al. (2010) and Talwar et al.'s (2011) findings that participation usually occurs in the later stages of the PIA process, our results show involvement early on and throughout the PIA process, including the foundational stage of problem definition (Fig. 4). Authors describe at least some stakeholder involvement in the initial problem definition and structuring stage of the PIA in 29 of 37 cases and in the goal and strategy or scenario identification phase in 30 of 37 cases. Participants were less involved in data collection (25 of 37 cases), model and/or tool development (17 of 37 cases), and the application of the assessment itself (10 of 37 cases), though they contributed to analysis of the assessment results in 24 of 37 cases. The tendency toward a stepwise, direct-use participatory modelling approach in the results may be explained by the community- to regional-scale focus of literature review, where the time and relational work required by direct participation methods may be more feasible than in larger-scale contexts.

3.1.2. Analysis, assessment and evaluation

Models are commonly combined with scenario analysis to facilitate comparison of the impacts of management alternatives or interventions under potential future conditions. Scenarios describe endpoints or visions for the future. Working backward, participants can use scenario characteristics to create a suite of possible indicators and policy options required to achieve these visions, with a model often employed to quantify impacts and clarify implications. We found that only 8 cases in the review explicitly describe a formal scenario development process in which participants are asked to consider and share a suite of future visions (Bohnet et al., 2011; Caille et al., 2007; Dymond et al., 2010; Inouye et al., 2016; Reinhardt et al., 2018). At the same time, however, 27 of 37 total cases outline the (more or less participatory) development of one or more management options to be evaluated through IAM in order to anchor a discussion of impacts and trade-offs, confirming a prominent focus on the analysis and comparison of alternative futures in PIA.

The three cases not including a modelling component at all adopt the Delphi technique and draw on publicly-available information to develop a community vulnerability index (Alessa et al., 2008); conduct an integrated literature review and participatory mapping and appraisal to improve scientific understanding of the case context (Janssens de Bisthoven et al., 2020); and use participatory methods to evaluate the impacts of an irrigation project on small-scale fishers and farmers (Nguyen-Khoa et al., 2005). These assessments notably take place at the community level, with Alessa et al. (2008) and Nguyen-Khoa et al. (2005) confirming that they intentionally accounted for communities' capacities and constraints in their project design - an important reminder that notwithstanding modelling's benefits, the development of an IAM can be a complex and resource-intensive endeavour that may not be suitable for every context.

A small proportion of cases (5 of 37 cases) integrated a Bayesian Network (BN) approach. (Carmona et al., 2013a, 2013b; Croke et al., 2007; Henriksen et al., 2007; Holzkämper et al., 2012). The BN approach represents the interactions between a set of variables, or nodes, through a directed graph that includes the possible values the variables may adopt and the relationships (strength of connection)

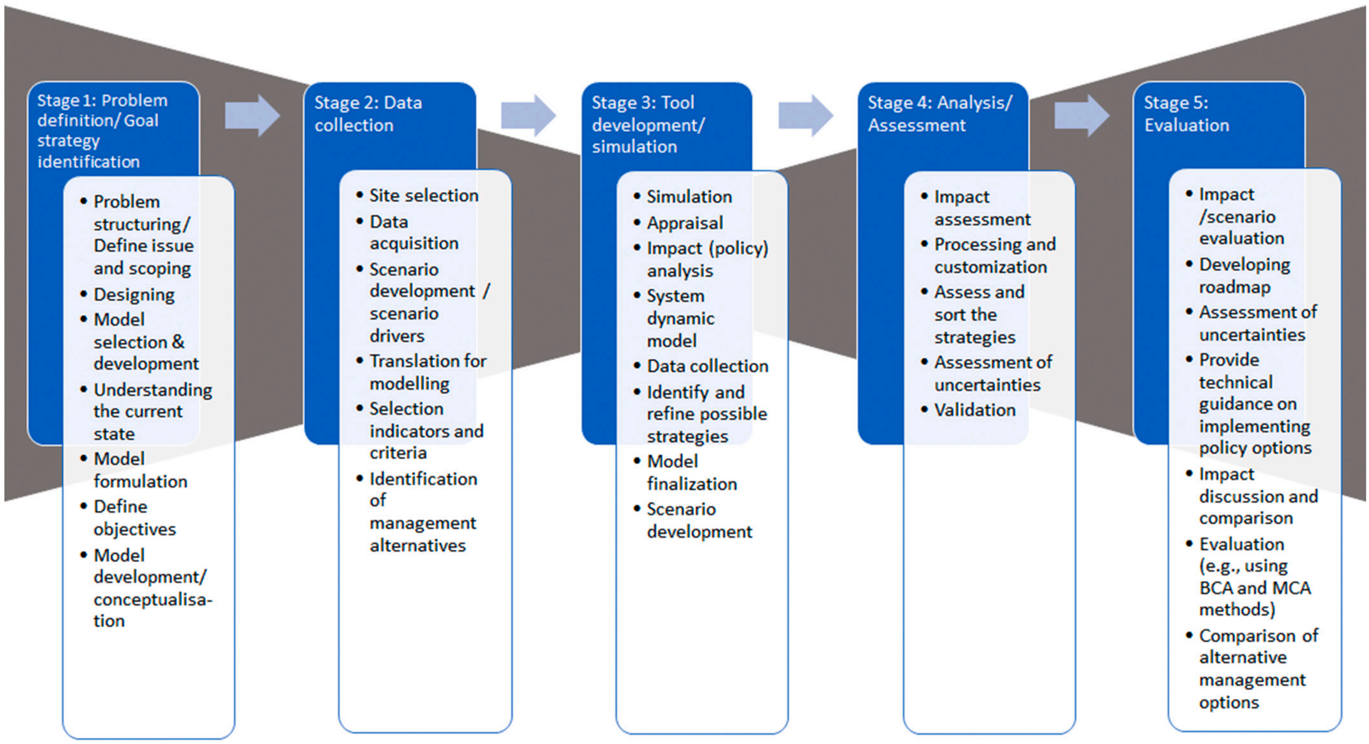

Fig. 4. Participation in PIA stages as depicted by the dark-coloured background.

between them, provided through conditional probabilities (Borsuk, 2008; Catenacci and Giupponi, 2013). Bayesian Decision Networks (BDNs) add decision variables, or policy or management alternatives, to the model in order to evaluate the probabilities of outcomes of a range of different interventions (Catenacci and Giupponi, 2013). BNs are attractive due to their relative flexibility, accessibility, and ability to clarify areas of uncertainty. For example, Holzkämper et al. (2012) and Carmona et al. (2013a, 2013b) employ the BN approach in the implementation of a "meta-model" which uses results from separate coupled models to populate a BN model. The authors praise the resulting BN models' ease of use, adaptability to different combinations of models and types of data, and explicit treatment of uncertainty, but also acknowledge the limitations of the approach: model variables are discrete and are unable to incorporate feedback loops, with revisions to the BN requiring updates or replacement of the original coupled models.

Gain and Giupponi (2015) alternatively address the issue of uncertainty through the use of multi-criteria analysis (MCA) (see also Allain et al., 2020; Bhave et al., 2016; Messner, 2007). MCA is a decision support tool that allows participants to rank or weight the relative subjective importance of different criteria or indicators used for IA (Lai et al., 2008; Scholten et al., 2017). Following the selection of a set of indicators in Gain and Giupponi's (2015) basin risk assessment, a group of expert stakeholders assigned numerical scores for relevance to different combinations of risk indicators, with the scores used to develop model parameters; the model results effectively represent uncertainty by incorporating stakeholders' different attitudes toward risk. Although the approach elucidates rather than fully settles areas of uncertainty, Gain and Giupponi (2015) note that the combination of quantitative indicators and stakeholders' subjective judgements offers a critical opportunity for stakeholder reflection and discussions concerning the integrated calculation of risk. Allain et al. (2020) similarly find that the addition of MCA to traditional modelling approaches provides a strong basis for discussion around the relevance and significance of the discourses underlying assessment results. Reflecting on the use of MCA in their PIA for the Spree and Schwarze Elster river basins, Messner (2007, p. 291) finally suggests that in the context of unsolvable uncertainty, the objective of IA should shift from "identifying an optimal strategy (assuming future certainty) toward identifying robust strategies, which deliver satisfactory results for a bundle of possible future development paths".

3.2. Outcome and uptake

Early reviews of PIA raise lingering questions regarding IA adoption and use/uptake by stakeholders and decision-makers (Salter et al., 2010). Our results validate these questions, with only 3 of 37 cases confirming stakeholder uptake of PIA outputs (Malve et al., 2016; Parker et al., 2014; Vogl et al., 2017). Authors in two other cases note that PIA outputs were not used at all - because there were no resources available for follow-up in Carmona et al.'s (2013b, 2013a) case, and due to a mismatch between stakeholder needs and project focus in Barthel et al.'s (2016) study. Although we intentionally screened for studies that included at least a cursory description of problem- or use-outcomes (beyond a discussion of empirical or technical results) in the literature review, the remainder of the studies present only brief anecdotal evidence of stakeholder response; the majority note positive stakeholder response throughout the duration of PIA projects but are unclear as to if and how that interest may later translate to use.

The lack of confirmed outcomes may in part be tied to a general absence of systematic or formal methods of evaluation and outcome measurement. Most cases focus on the accuracy of IA model results based on both internal validation and calibration and external feedback. To account for external feedback, most of PIA projects follow an iterative process in which researchers present results to stakeholders at progressive stages in the assessment process, with stakeholder feedback incorporated into tools and models following each stage. Researchers additionally summarise outputs with stakeholders at the end of the project to confirm the accuracy and relevance of results (Hewitt et al., 2014; e.g., Holzkämper et al., 2012; Letcher et al., 2004; Malve et al., 2016; Marcotte et al., 2020; Serrat-Capdevila et al., 2013). Beyond empirical validation, however, only a small number of projects (14 of 37 cases) include an internal or external evaluation process to assess the broader PIA process and outcome; of these, four are part of the same study seeking to refine scenario tools through a comparative assessment of their performance in practice (Reinhardt et al., 2018). In the projects that do conduct a formal evaluation, the most common tools are questionnaires and interviews that measure indicators such as PIA credibility, usefulness, and potential for capacity-building as well as changes in stakeholder knowledge and perceptions (Alessa et al., 2008; Barthel et al., 2016; Carmona et al., 2013a, 2013b; Cohen, 1997a, 1997b; Cohen and Neale, 2007; Gain and Giupponi, 2015; Henriksen et al., 2007; Nguyen-Khoa et al., 2005; Reinhardt et al., 2018; Serrat-Capdevila et al., 2013). In order to capture medium- and longer-term outcomes, Inouye et al. (2016) and Vogl et al. (2017) state that they plan to monitor ecological and socio-economic outcomes and assess stakeholder knowledge and social learning through future evaluations.

Research-practice gaps in PIA outcome and evaluation may in part be a function of the slippery and intangible nature of potential PIA outcomes such as knowledge transfer, social learning, and network-building (Croke et al., 2007; Ernst, 2019; McIntosh et al., 2011; Salter et al., 2010; Scherhaufer, 2014). Difficulties in procuring resources for project follow-up also present issues for long-term evaluation of outcomes (Barthel et al., 2016; Carmona et al., 2013b; Serrat-Capdevila et al., 2013), while project and publication timelines may preclude a systematic analysis of outcomes, particularly in those cases where authors are reporting on the development of initial or prototype tools (e.g., Bohnet et al., 2011; Holzkämper et al., 2012; Letcher et al., 2004; Malve et al., 2016). In any case, the lack of details on uptake and use presents ongoing challenges for a comprehensive analysis of PIA outcomes, implications, and success factors.

4. Discussion

4.1. Advancing integration in integrated assessment

The results of our review concur with the observation by Zare et al. (2017) that more integration is still needed in the fields of IA and PIA. PIA has done much to incorporate the "human dimension" of environmental issues into IA by inviting stakeholders to take part in the assessment process (Kloprogge and van der Sluijs, 2006; Salter et al., 2010; Scherhaufer, 2014). Nevertheless, Zare et al. (2017) note that while the dual consideration of biophysical and socioeconomic elements is increasing in the field of integrated water resources management, biophysical dimensions continue to take precedence; integration of social fields currently takes place primarily through the lens of economics, with less attention given to fields including law, policy, and stakeholder participation. Indeed, the majority of our cases include an economic component through the implementation of an economic model and/or cost-benefit comparisons between different management alternatives (e.g., Bohnet et al., 2011; Carmona et al., 2013b; Dymond et al., 2010; Letcher et al., 2004; Messner, 2007; Newham et al., 2007; Vogl et al., 2017). Integration is also evident across the sectors of agriculture and water resources management (e.g., Ballé-Béganton et al., 2012; Carmona et al., 2013a; Henriksen et al., 2007; Malve et al., 2016; Newham et al., 2007; Reinhardt et al., 2018). Drastically fewer cases attempt to explicitly incorporate less easily-measured social inputs and indicators such as cultural, institutional, and knowledge capacity or the policy and governance context of the case locations.

4.1.1. Explicit integration of social dimensions

Social and/or qualitative dimensions may undoubtedly be more challenging to measure and model in quantitative and numerical terms than biophysical factors (Reinhardt et al., 2018). To compound this issue, Ballé-Béganton et al. (2010) explain that there is a trend in existing modelling projects for researchers to establish links to socio-economic modules after they have already started building the integrated model from environmental models, leading to poor integration of socio-economic dimensions in the final model. Letcher et al. (2004) flag the bias in IA toward biophysical system perspectives, and the resulting exclusion of social scientists in early IA conceptualisation and development, as a potential reason for the gap. The authors caution that the problem definition, and not a particular discipline, should lead the development of an IA, while Ballé-Béganton et al. (2010) suggest adopting a top-down approach - that is, considering the socio-economic aspects of the issue before choosing which models to include in the assessment so as to ensure that the models are appropriate for the task. One way to align the model framework with the socio-economic landscape of the stakeholders is to co-develop the conceptual models with them (Villamor et al., 2020) and continue involving them up to the last stage of the PIA process, including the uncertainty assessment (Refsgaard et al., 2007).

Given these trends, alongside the dominance of computer- and expert-generated models as a tool for IA and PIA (Salter et al., 2010), it is not surprising that most studies adopt a primarily biophysical/economic lens. Allain et al. (2020) find that the mere presence of a model implicitly encourages stakeholder use of "efficiency"-oriented narratives and a reliance on scientific and expert knowledge (instead of equity, honesty, and other important considerations) as the benchmark for consensus, regardless of the model's objective or inputs. However, Inouye et al. (2016, p. 290) remind their readers that the concept of modelling encompasses "any simplified representation of a system that involves relationships among different entities within a boundary" and may be expressed in qualitative, quantitative, or combined formats. The authors include a quantitative model in their PIA project, but begin with a conceptual, hand-drawn model that allows stakeholders to consider their desired futures in a space that is free from quantitative constraints. Alessa et al. (2008) and Gain and Giupponi (2015) likewise attempt to incorporate indicators for social dimensions of risk and community capacity in their PIAs evaluating community resilience and vulnerability. The authors assess indicators including knowledge, institutional, and cultural capacity through measurements such as number of elders in a community, length of residency in a community, and strength of social network linkages. These cases still constitute the exception instead of the rule, confirming the fact that the "integration" component of IA is an area that requires urgent attention if researchers and practitioners wish to achieve truly holistic, supported solutions to environmental and resource management issues.

4.2. Entry and exit planning in PIA: What for and what next?

Our review indicates that the success of empirical PIA processes and outcomes often hinges on the strength and extent of entry and exit planning. A first key lesson for project planners is to clearly identify their audience and goals, then design and implement the PIA accordingly. Barthel et al. (2016) explain the lack of stakeholder uptake of outputs in their PIA resulted from a mismatch in project objectives and stakeholder needs. The PIA included two laudable goals: first, to advance scientific research on the topic of the regional-scale impacts of global change processes and second, to implement a decision-support model in actual management contexts. However, the level of model resolution and complexity required to achieve the first goal ultimately clashed with participants' desire for a user-friendly tool applicable to their local situation and discouraged stakeholder interest and uptake. Tools should instead be developed using a targeted approach with the aim of achieving fit for (very clearly defined) purpose, incorporating considerations of geographical scale, case conditions, and stakeholder capacity (Alessa et al., 2008; Malve et al., 2016; Marcotte et al., 2020).

A tailored approach necessarily means that any one PIA will not and cannot achieve all objectives for all participants. Specific goals, capabilities, and constraints of the project and tools should be communicated to participants at an early stage to help manage expectations. Project framing can likewise encourage or hinder participation in PIAs; several authors note a lack of urgency on the part of potential and actual participants resulting from the disjuncture between projects developed around abstract global issues such as climate change and the more tangible, short-term evidence or impacts that may already be felt by participants at the catchment or community level (Barthel et al., 2016; Cohen and Neale, 2007; Henriksen et al., 2007; Inouye et al., 2016; Messner, 2007).

Crucially, researchers and project planners should also remain aware of the limits and opportunities of PIA in the first instance. Although Croke et al. (2007) agree that assessment tools can provide general guidance on the trade-offs associated with different management interventions, they and several others note that PIA's greatest value lies in the process instead of its specific outcomes or outputs. Beyond quantitative outputs or predictions, process outcomes may include social learning, networking and communication, the development of collective understanding and knowledge or knowledge co-production, the discovery of data and knowledge gaps, and/or the revelation of new information on participants' biases and assumptions (Ballé-Béganton et al., 2012; Caille et al., 2007; Cannata et al., 2018; Carmona et al., 2013a, 2013b; Janssens de Bisthoven et al., 2020; Marcotte et al., 2020; Reinhardt et al., 2018). Within international science and policy fora there is a growing expectation that shifting toward co-production will enable science to have greater impact on sustainable development outcomes (Norström et al., 2020). Co-production may lead to knowledge that might not bring breakthroughs on the generic, science-based understanding of underlying issues, but it is more likely to be seen as 'usable' knowledge in the local context.

Matching project outputs with objectives also calls for a flexible, iterative approach to ensure that processes and outcomes can be aligned with stakeholder needs and any shifts in the case context. In Inouye et al.'s (2016) assessment, this involved suspending the development of a systems dynamic model mid-project in order to focus on an integrated model more suited to stakeholders' needs and feedback. Letcher et al. (2004) similarly conducted additional land-user interviews at their case site to assuage emerging stakeholder concerns about initial model assumptions. Openness to participant feedback alongside meaningful inclusion in all stages of the PIA helps participants develop trust, confidence, and a sense of ownership in project outputs, even when the results are unexpected or unfavourable to certain stakeholder groups (e.g., Bohnet et al., 2011; Croke et al., 2007; Hewitt et al., 2014; Newham et al., 2007; Serrat-Capdevila et al., 2013).

There are trade-offs associated with the accuracy versus accessibility of PIA tools, but the case results suggest that simpler tools generally facilitate more interest in outputs and uptake. Letcher et al. (2004) and Newham et al. (2007) advise starting simple and adding complexity if and when it is called for by the participants and context. Accessibility in other areas may involve the use of free modelling software, the development of visual tools and interfaces, and plain-language formatting and correspondence (Ballé-Béganton et al., 2012; Caille et al., 2007; Cannata et al., 2018; Cohen, 1997a, 1997b; Holzkämper et al., 2012; Parker et al., 2014). Including stakeholders with decision-making power or broker capacities in the PIA can further encourage later uptake and provide access to a wider range of stakeholders, but projects should be cautious of overreliance on a single entity in case of institutional restructuring (Croke et al., 2007; Newham et al., 2007). In all cases, researchers should already be including provisions for project follow-up and maintenance in the early planning stages of the PIA in order to encourage ongoing use of the outputs and tools in real-world management contexts (Barthel et al., 2016; Malve et al., 2016; Serrat-Capdevila et al., 2013).

4.3. Boundary work on issue cycles

In relation to the boundary work concepts (linking knowledge to action) and the multiple constraints to progress in issue cycles, further reflection may be needed on what PIA is supposed to help with, and what it can actually do in diverse contexts (Fig. 6). The emphasis in most of the case studies has been on the cognitive side (A), setting the scene for the more political search for coalitions that can frame common goals (B) and the distributional aspects of a common but differentiated responsibility for means of implementation (C). An important long-term benefit of a PIA process can be that it facilitates a way of monitoring subsequent change that is credible, salient, and legitimate (D). Benefits for aspect D require a long timeframe to observe and evaluate impacts.

Fig. 6. The multiple challenges that need to be overcome before a new "issue" is sufficiently understood (A), accepted as target for goals (B), attracts appropriate means of implementation (C), and has a monitoring system that allows innovation (D) (based on van Noordwijk, 2019).

Further analysis of PIA cases in terms of the complexity they dealt with (e.g., how far where knowledge systems apart? How strong was the initial denial reaction? Conspiracy theories? Blame games?) could lead to a better-informed reflection on the contributions PIA made (e.g., in progress along the four ten-point scales for A through D proposed by van Noordwijk, 2019).

4.4. Accounting for the human dimension

Given PIA's interest in not only outcome but also the assessment *process* itself, relationships and trust within and between stakeholder and researcher groups become paramount to smooth project functioning and ultimate uptake of PIA outputs. Most of the studies we review suggest the same, but simultaneously lack comprehensive detail on how to foster and navigate stakeholder relationships, particularly in cases with the potential for conflict or power differentials. Scherhaufer (2014, p. 458) posits a few potential reasons for the discrepancy: first, successful (and thus published) instances of PIA may rely on "already communal interests" so as to ensure that projects avoid deadlock, and second, there is a tendency to include a relatively homogenous group of well-organised stakeholders from scientific, public, or semi-governmental backgrounds.

Participants in the cases primarily comprise national, regional, and local government agencies and varying representation from landholders, land users, researchers, and industry and environmental associations, with the most common point of conflict flagged as competing land uses (e.g., Allain et al., 2020; Carmona et al., 2013a; Nguyen-Khoa et al., 2005; Reinhardt et al., 2018). Messner (2007) notes that stakeholder friction in the first year of their project slowed overall progress, and Carmona et al. (2013a) find that environmental groups had a lower level of satisfaction with their project's participatory modelling process than farmer participants, who traditionally hold more influence at the case site (see also Henriksen et al., 2007). Conversely, Inouye et al. (2016) confirm that their PIA benefited from a situation in which conflicts around competing water uses were not yet so severe as to prevent stakeholders from working together. A short project timeframe generally appears to limit the amount of relationship-building that can take place (Cohen, 1997a, 1997b; Croke et al., 2007), while time investment, community presence, the use of local champions or brokers, and open and regular channels of communication contributes to participant collaboration, engagement, and trust in the PIA process and outputs (Carmona et al., 2013a; Letcher et al., 2004; Newham et al., 2007).

Nguyen-Khoa et al. (2005) provide the most detailed description of methods to address stakeholder conflict and power imbalances. Recognizing the tension between farmer and fisher participants at their case site, the researchers allowed the less-influential and more inexperienced fishers extra time to state their positions at workshops and invited them to participate in additional briefings and confidence-building exercises. The result was an outcome in which fishers were given adequate representation relative to their starting point and fisheries were acknowledged as an important component of water management issues in the catchment - a seemingly small but previously unthinkable concession. Newham et al. (2007) likewise target different participatory methods to different groups of stakeholders, while Marcotte et al. (2020) make an extra effort to include stakeholders unable to attend workshops due to logistical challenges and/or resource constraints, holding separate meetings with indigenous groups in their own communities.

These and other approaches may go some way in addressing existing power differentials and areas of conflict while achieving a relatively more representative PIA process and outcome. In cases where power-sharing or co-determination is not possible, researchers should, at the very least, remain cognizant of the resulting limits of the participatory process, in which outputs will inevitably vary depending on the participants involved (Caille et al., 2007; Croke et al., 2007). Scherhaufer (2014, pp. 460–461) thus suggests:

> A good starting point would be to accept that when only a tiny group of non-representative stakeholders is engaged, the legitimate provision of information and explanation is limited to a very small decision-making context … Consequently, the integration of stakeholders … should be limited to closely defined goals such as increasing the depth of information or sensitizing participants or scientists, rather than aiming at social learning or enhancing the legitimacy of a process.

5. Conclusions

We conducted a systematic literature to update and deepen our understanding of the approaches, methods, opportunities, and challenges associated with PIA as applied at the catchment scale. Our final review complements the results of earlier reviews of the field (Kloprogge and van der Sluijs, 2006; Salter et al., 2010; van Asselt and Rijkens-Klomp, 2002); of the 37 cases we analysed, the majority employed some combination of agent-based models covering hydrology, agriculture, landscape, climate, economics, population, and more. A small but notable group of cases also incorporated tools such as Bayesian networks and/or multi-criteria analysis in order to account for factors that other modelling approaches may miss. The key and obvious difference between the 37 PIAs implemented in the cases and conventional IA is the deliberate invitation to stakeholders to join the assessment process. Participatory activities were most often iterative in nature, with participation generally occurring early and consistently throughout the assessment process, though we noted less participation at the data gathering, tool development, and analysis stages of the PIA. The “stakeholders” in the cases included local, regional, and national government agencies with additional representation from industry, non-governmental organisations, and land-users. While a small number of authors note former or current areas of conflict between participant groups, the conflict was not reported as severe enough to derail the PIA process.

Based on the results of the review, we agree that PIA is a potentially useful tool for navigating the dual, intertwined social-ecological dimensions of current environmental and natural resource management issues, and a powerful tool for facilitating stakeholder trust and learning as well as increasing the credibility, legitimacy, and uptake of project outputs. However, our review also highlights the additional work that is needed in order to advance PIA as a truly effective approach to addressing challenging environmental issues. Thus, a more comprehensive analysis of PIA outcomes may therefore require a review of any existing follow-up publications to the cases that provide a more comprehensive reporting of stakeholder uptake or behavioural change. We might also expand our search criteria to include PIAs implemented at geographical scales larger than the catchment scale to see if our findings remain the same across different contexts. At the same time, an assessment of impacts stemming from the PIA process requires that researchers plan for and incorporate a formal or informal evaluation framework in their projects in the first place, and we find that this is an area that is still severely lacking.

Our review thus indicates both the opportunities and the limits of PIA as currently implemented. We see PIA as an important tool in a larger governance and management toolbox - a tool that is used most effectively to provide starting points for discussion and general guidance on management alternatives. Further exploration of the gaps outlined above may help advance PIA further, concerning both its integrative reach and the still-murky relationship in the field between processes and outcomes.

CRediT authorship contribution statement

Grace B. Villamor: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Lisa Sharma-Wallace:** Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Meine van Noordwijk:** Investigation, Writing – original draft, Writing – review & editing. **Tim Barnard:** Conceptualization, Formal analysis, Investigation, Project administration, Writing – original draft, Writing – review & editing. **Dean F. Meason:** Conceptualization, Funding acquisition, Project administration, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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