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Helping to Build Stock Assessment Capacity in Australia: A Case Study

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ABSTRACT

Fisheries stock assessment capacity faces resource constraints in many countries, including limited personnel, high workloads, and restricted funding. Stock assessment scientists often operate under short timelines, with outcomes that can influence livelihoods and receive public scrutiny. Scientists frequently manage multiple assessments each year, making time management a challenge. Consequently, finding opportunities to invest in professional development remains difficult within existing operational demands. We developed a series of approaches to invest in Australia's employed stock assessment capacity, and present these as a case study for other similar marine science fields and countries. The approaches led to critical insights to a way forward to develop a 'Community of Practice'. We used network analyses to evaluate collaboration based on published Australian stock assessments and related papers. We then used surveys and interviews to understand the factors that have constrained stock assessment scientists in investing in their own development. Tools and opportunities were then made available: (a) a web site providing a central repository on freely available stock assessment packages and Australian stock assessment reports; (b) training courses on the use of assessment packages that were open to participants across organisations; and (c) a simulation game to learn in a 'consequence free' environment. This paper highlights what has been learnt and generalises these findings beyond the Australian stock assessment community's well-being.

1 | Introduction

Stock assessments are analytical processes that support fisheries managers by identifying whether overfishing is occurring or a stock is in an overfished state (Hilborn and Walters 1992; Cope 2024). They also provide information for setting or adjusting the management measures required to achieve management objectives. The field of stock assessment is inter-disciplinary and requires knowledge of biology, statistics, mathematics, applied modelling techniques, and fisheries management. As such, it is highly specialised, with a relatively small global group of practitioners. Moreover, the number of fished stocks—and those that require regular status assessment to avoid undesirable consequences to stock sustainability—greatly outnumbers the stock assessment community of practitioners (Cope et al. 2023; U.S. Dept. of Commerce 2008).

Australia is fortunate to have an, albeit small, pool of well-respected stock assessment scientists to provide expertise both domestically and internationally. However, this is still insufficient to meet the needs of all Australian fish stocks requiring assessment (Dichmont et al. 2016). In addition, there are the logistical challenges of a large country and of geographic distances between groups. In common with many countries that have multiple layers of government, Australian fisheries are managed by either State or Commonwealth (federal) jurisdictions as detailed in the Offshore Constitutional Settlement (Anon 1980). Each jurisdiction has its own fisheries management policies and legislation. Thus, even though there are similar underlying principles within each, the jurisdictions differ in important ways and have their own preferred science research provider that employs stock assessment scientists (Dichmont et al. 2021). Consequently, the stock assessment community is jurisdiction-focused and dispersed across a large country where travel is expensive and time-consuming. Historically, this jurisdictional focus and distance has led to barriers to interaction, which may still persist.

Unlike many countries where fisheries management is mainly resourced through government core budgets, Australia uses cost-recovery from industry as the key source of funds for stock assessment (Anon 2023). This means that smaller, less valuable fisheries tend not to have large budgets for stock assessment and monitoring. Australia has many small, low value stocks but high policy requirements for their management. This conundrum of high demands but relatively low funding means that stock assessment scientists have little time to develop their own skills, and if they do, often find it hard to obtain the funds to connect with others to learn new skills. This problem is much more pronounced in the smaller jurisdictions where small teams need to be experts in multiple fields and cannot truly become specialists (Pascoe et al. 2025b). Larger organisations with a greater number of professionals can grow their expertise within the organisation, but this can lead to a self-perpetuating system where their organisation is an attractive employer because of the expertise of their staff. These factors all contribute to collaboration being mostly in-house and even within teams.

Lack of collaboration, or isolation, can lead to inefficiencies, such as building multiple bespoke stock assessment modelling platforms that are essentially redundant or creating multiple approaches to addressing essentially similar problems (Dichmont et al. 2021), or limited sharing of advances and new approaches. In addition, the lack of a 'team effort' within or between organisations can mean that best practices are not always followed (Punt et al. 2020; Cope 2024), and errors are not detected. A lack of information sharing further means that there may be few mentors or sources of assistance available for those in this field, resulting in errors, inefficiencies and lack of capacity building. A sense of isolation can also lead to diminished job satisfaction.

Stock assessments play a critical role in fisheries management and the implementation of harvest strategies. A decline in assessment capability can have cascading effects on other aspects of management. For instance, reduced confidence in stock assessments may lead to more precautionary management measures, potentially affecting the fishery's economic viability. However, stock assessment is just one facet of a broader system of interdependencies, including data quality. In this paper, we present the perspective of stock assessors.

Of relevance is that Australia does not have a dedicated graduate or postgraduate fisheries stock assessment training programme, which builds in-depth knowledge of stock assessment. The issue is again geographic, as well as due to the university funding model: despite national demand, there is no regional demand for universities to provide stock assessment training. This means Australia tends to train stock assessment scientists from other related fields post-university in their workplace on an *ad hoc* basis or rely on attracting stock assessment scientists from other countries.

The USA National Oceanic and Atmospheric Administration (NOAA) Fisheries program released an update to its Stock Assessment Improvement Plan in 2018 which provides a framework for implementing a Next Generation Stock Assessment framework (Lynch et al. 2018). The update highlights key challenges, including the need to develop best practices for fully integrated ecosystem and socio-economic data, approaches to comprehensively characterise assessment uncertainty, and how to address bottlenecks in the assessment process. It also advocates for more holistic and ecosystem-linked assessments, innovative science in data collection and analysis, and greater efficiency in using available resources to deliver timely results to fishery managers and the public. In addition, Lynch et al. (2018) emphasises the importance of collaboration in achieving these goals. In terms of collaborative assessments and, through that delivering best practice, Australia still has barriers (internal and external) to overcome before collaboration becomes the norm. This study is a step toward this goal.

Scientific productivity—defined as the relationship between inputs and outputs—is influenced by various factors, including human resources, capital investment and infrastructure elements such as education and training (Chou et al. 2008). In addition, the advancement of technological capabilities relies on collaboration and the establishment of strategic partnerships (Madanmohan et al. 2004). From an individual scientist's perspective, social connections and collaborations play an important role in both well-being and research output (Amabile and Kramer 2011). Organisational studies further highlight that well-being contributes to work-related outcomes, such as performance and creativity (García-Buades et al. 2019; Salas-Vallina et al. 2018). In this context, well-being encompasses essential components such as training and collaboration, which are integral to professional development (Godliauskas and Šmite 2025).

This paper, therefore, focuses on the role of training and collaboration in fostering well-being that is in the control of the individual and, if relevant, employers. We present a roadmap as to how Australia can nurture and maintain a robust, skilled and connected staff of stock assessment scientists. We describe an experimental approach to connect the existing employed (as opposed to student) Australian stock assessment community and build their capacity and ability to collaborate. This paper provides an overview of a body of work from the authors where the details are published (Pascoe et al. 2025a, 2025b; Punt et al. 2025; van Putten et al. 2025). This is not about employing more people

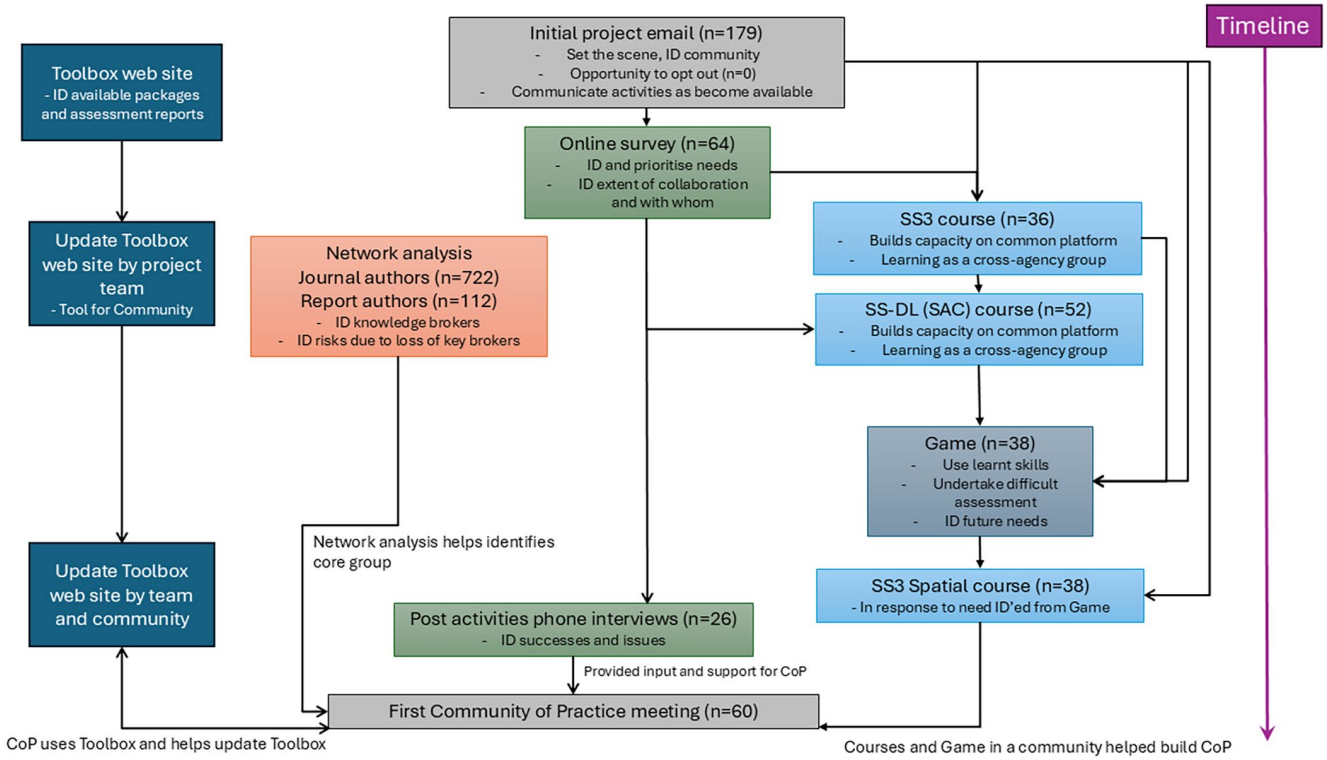

FIGURE 1 | Flow diagram of study activities and their linkages. The numbers involved in each of the groups are provided in brackets.

(which is unrealistic in the Australian funding environment), but growing existing capacity by developing new skills, sharing knowledge and better connecting the current community. The paper is also not about appointing blame, but rather fostering well-being and skills to overcome challenges such as data quality and quantity. By improving the accessibility of training, and connecting and upskilling scientists, the aim is to provide a conduit to create a connected and collegial community that can attract and retain the next generation of Australian stock assessment scientists to support evidence-based management decisions.

2 | Overall Design

To invest in the current stock assessment community, we designed four streams of activities and identified what could be learnt from each (Figure 1). These activities were: (a) identifying the knowledge brokers and how the community connects among itself and with those leaders (orange), (b) learning in a community (light blue), (c) creating tools and resources (dark blue) and (d) learning from play (grey-blue). The latter three activities had the dual objectives of providing training and resources to help build capacity and connect the community, and enabling the project team to learn about how best to create and build a stock assessment community.

The project followed a structured sequence, by design. First, key dependencies on individuals and the extent of cross-jurisdictional interactions was assessed using network analysis. Next, an email list of stock assessment scientists was created, and those on the list were invited to participate in project activities. An 'opt-out' system was used. Participants completed a survey to identify and prioritise needs, assess collaboration levels, and determine key partners (teams, organisations, Australia or worldwide), which informed training requirements. Courses (based on expressed needs from the survey) were made available to all on the email list to encourage broader interaction. A simulation stock assessment game ('the Game') allowed scientists to apply their skills, tackle an extremely difficult assessment in a safe environment, and identify further needs. This led to a follow up training course. The web-based Toolbox (https://toolbox.frdc.com.au/), which contains information on assessment packages and reports, was updated throughout the project—initially by the project team members and later collaboratively with the assessment community. Finally, the success of the project was assessed through interviews with a subset of online survey respondents who had agreed to participate at the study's conclusion.

3 | Knowing the Knowledge Brokers and Community Connections

The first pillar is understanding the current environment in which stock assessment scientists operate: the knowledge brokers, barriers and other constraints to connections and aspirations. This involved two activities: an assessment of current connectiveness using network analysis; and two surveys (an online survey and a series of video/telephone interviews) of stock assessment scientists to understand their perceptions of these factors limiting connections. The surveys and interviews were approved by the CSIRO Social Science and Human Research Ethics Committee (001/23).

3.1 | Network Analyses

We undertook network analyses based on journal publications in the field and stock assessment reports from the grey literature (van Putten et al. 2025) to understand who the Australian knowledge brokers in the field were, as well as the people who best connect the community. van Putten et al. (2025) examined the connections within the stock assessment community and identified the key influencers and knowledge brokers involved using network statistics for the journal article author network and assessment report author network: (a) for the networks as a whole and (b) for individual Australian authors.

The assessment report author network (the 'grey' literature) highlighted a general lack of connection among organisations. However, there is a central person (presumably an expert) within each of the three largest sub-networks, who works across multiple species and thus unites the other species-specialised co-authors. In contrast, the author network for journal articles (see Figure 4 in van Putten et al. 2025) was much denser (i.e., more authors and more connections) than that for the assessment reports. There were stronger clusters of co-authors around certain central authors and more connected components than for the assessment report author network (Table 1). There were many international co-authors in the Australian stock assessment network distributed over many institutions.

One organisation plays a central role in the network, employing many authors who have a high betweenness centrality (i.e., the author acts as a bridge (Wasserman and Faust 1994) and connects with many authors from different organisations (and in some cases, countries)). One person (not identified due to ethical restrictions) stood out both in terms of having the highest number of papers, and the highest betweenness centrality (Table 2). Betweenness centrality measures the number of times an author lies on the shortest path between others (i.e., the author acts as a bridge). A high betweenness count could indicate someone holds authority over disparate clusters in a network, or just that they are on the periphery of both clusters (van Putten et al. 2025). In this case, it is the former. Moreover, this person's betweenness centrality was substantially higher than that of the second-ranked author. The top-ranked authors are the leading brokers in the network and collaborate with people who may not collaborate with others[1].

A sensitivity analysis was conducted that excluded the papers of the top five authors (as first or co-authors), based on a high number of co-author interactions from the journal network analysis. The network was less clustered without these top authors, that is, the remaining authors would be even less interconnected, forming tighter knit but more discrete groups. This suggests that the top authors likely facilitated connections among groups, and their removal would result in a more fragmented network. It is important to note that the top five authors have naturally taken on a role of facilitating collaboration among others. Essentially, these authors organically became central figures in the network of collaborators because of the way their work and interactions developed, not because they were specifically chosen or appointed to be leaders.

The role of one organisation would persist in this 'new' network (with the top five authors removed), with the top five authors in this 'new' network being affiliated with this organisation. This highlights the importance of one main organisation in Australia and indicates that the top authors remain key to the long-term connectedness of the community. Therefore, building new leaders (particularly from other organisations) is an essential component of maintaining connections within the community. This is especially important given there is an increasing risk of losing the current knowledge brokers due to, for example, retirement or corporate restructure. There is a case for a formal role of leaders that could provide enduring connections.

The list of authors from the network analyses was used to create an email communication list of stock assessment scientists for the subsequent activities. Authors were asked permission to be on the list. Requests for additional names meant that the list increased slightly over time. No one requested that their name be removed, confirming the expectation that the Australian stock assessment community sees value in additional collaboration and trusted the project team.

TABLE 1 | Network statistics for peer-reviewed journal articles and assessment reports (reproduced from van Putten et al. 2025).

Network statistic	Journal articles	Assessment reports
Number of nodes	722	112
Number of edges	7819	802
Average number of neighbours	19.433	8.364
Network density	0.029	0.195
Clustering coefficient	0.842	0.823
Network diameter	9	4
Characteristic pathlength	3.152	2.382
Connected components	11	10

3.2 | Pre- and Post- Project Surveys

Using the list of stock assessment scientists identified in the network analysis as invitees, an online survey was undertaken before any of the activities/opportunities commenced. The online survey was developed with the primary aim of understanding how stock assessment scientists gain and share their expertise, and the factors influencing the choice of whether they use bespoke modelling approaches or stock assessment packages, aka model choice. The survey consisted of several components (Pascoe et al. 2025a) to understand model choice, degree of collaboration, and barriers to collaboration.

Those undertaking the online survey (anonymously) were asked if they were willing to be part of a post-activities survey interview (and if so, were requested to provide their contact details and names). The follow-up survey, in the form of semi-structured video/phone interviews using Microsoft Teams, was undertaken at the end of the 2-year set of activities, using those

TABLE 2 | Impact factor and citations for the top 15 first authors (only ID number shown) who have the highest number of co-authored publications between 2012 and 2023.

First author	Number of 1st authored papers (2012–2023)	Average journal impact factor (2012–2023)	Max of times cited for any one paper	Betweenness centrality
ID558	23	3.267	381	0.135
ID542	10	3.366	247	0.102
ID149	10	3.319	62	0.073
ID158	8	4.413	69	0.092
ID524	7	6.431	30	0.019
ID766	7	3.967	35	0.023
ID443	5	6.581	15	0.052
ID093	4	4.553	27	0.031
ID348	4	4.095	12	0.015
ID297	4	3.682	162	0.017
ID264	3	4.803	11	0.047
ID283	3	4.707	38	0.041
ID300	3	4.522	10	0.011
ID208	3	4.315	197	0.008
ID256	3	3.679	3	0.011

scientists from the first survey who consented to participate in the follow-up survey. The interview gave participants a chance to elaborate on some of their survey responses and determine whether the intervening activities had increased their perception of their skills and ability to collaborate outside their team. To conduct the interviews from an informed position, the follow-up surveys were conducted after an initial analysis of the online survey results, so that the interviewers could remind interviewees of their responses to the initial survey.

From the first survey, the scientists self-identified as being members of one of the following four groups: stock assessment package developer, bespoke stock assessment modeller, stock assessment modeller, or stock assessment model user (Pascoe et al. 2025a). The first three groups were combined due to low numbers in the package developer group. All groups identified the development of a Community of Practice (CoP) as being the most important/preferred approach to foster greater collaboration, but also highlighted the importance of regular face-to-face meetings and conferences. Online approaches to develop greater collaboration were generally considered the least beneficial approach.

The survey results showed that the training needs of the three groups would have some overlap; however, there were major differences. For example, those who self-identified as model developers were the largest users of bespoke models, but also collaborated more internationally than model users (Figure 2). The model developers would benefit from training in modern coding languages such as Template Model Builder (TMB; Kristensen et al. 2016) and from following best practices so that they can stay up to date. Model users with the lowest self-assessment of their ability worked with the fewest bespoke models and, by inference, mainly worked with packages to undertake stock assessments. Model users were the most isolated, working mainly within their team. This suggests that model users would likely benefit from training in multiple packages and stock assessment practices.

4 | Learning in a Community

Australia does not provide direct university training for conducting stock assessment per se. Rather, certain universities provide several quantitative options at the graduate or postgraduate level, for example, the Quantitative Marine Science PhD program at the University of Tasmania (https://www.imas.utas.edu.au/qms). This means that new stock assessment scientists with Australian university qualifications often need to learn the direct stock assessment skills on the job. Several organisations have provided training in stock assessment tools, but most of these have been in-house. One way of supporting these efforts and further building connections within the Australian stock assessment community is to facilitate access to training courses with objectives that include teaching the mathematical/statistical aspects of stock assessment, training in a specific stock assessment tool or method, and connecting scientists by making the courses open to the whole community. The intention of delivering open training courses was to examine whether an approach to learning in a broader community context would have enduring benefits of collaboration and sharing.

We facilitated access to three courses. The whole Australian stock assessment community was made aware of opportunities equally. Everyone was able to self-select the activities or

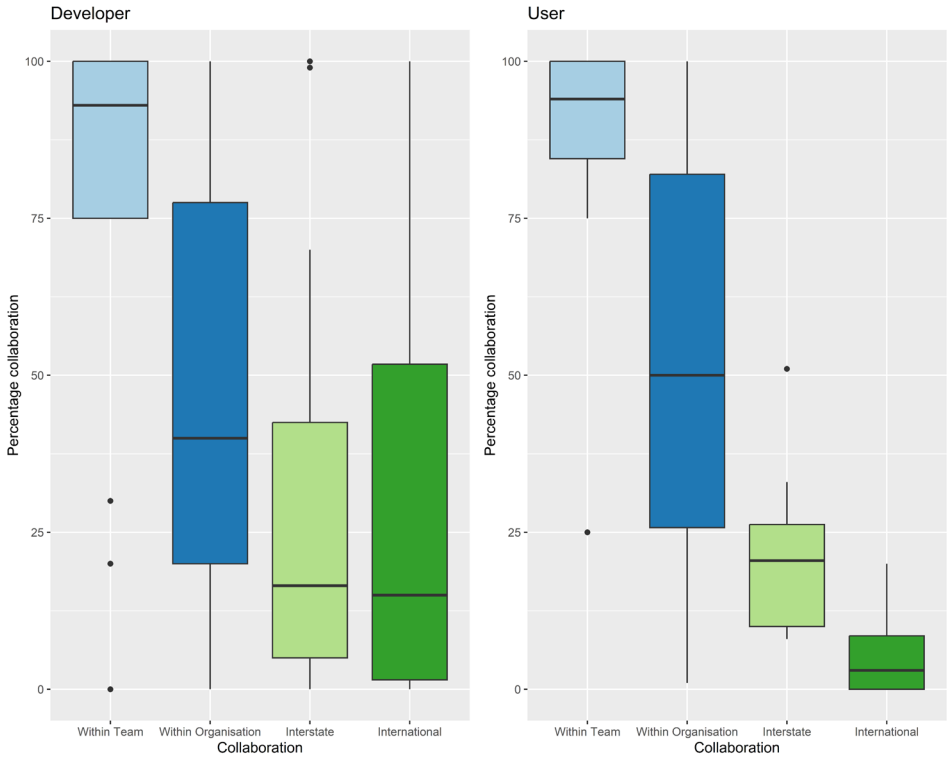

FIGURE 2 | Collaboration links from survey respondents classified as model developers ('stock assessment package developer', 'bespoke stock assessment modeller', 'stock assessment modeller') and model users.

opportunities with which they engaged, based on their own (or organisation's) need, interest and available resources.

The first was a Stock Synthesis 3 (SS3) (Methot and Wetzel 2013) course in Perth that had initially been intended to be held and funded in-house within the Western Australian Government fisheries research laboratory. We then funded two courses on the Stock Assessment Continuum Tool (SAC tool; Cope 2024) by flying the developer to Australia. Although not chosen via a formal training needs analysis (e.g., Barbazette 2006), the project team selected the SAC Tool because an investigation of past courses revealed there was an emphasis on advanced and data-limited assessment approaches, but that few trainings focused on data-moderate approaches. The SAC Tool can be used across the whole assessment continuum (hence its name) from data-limited to data-rich, and is highly flexible in terms of model specification capability, as it is underpinned by SS3 (Cope 2024).

We used the email list created from the network analyses to reach out to potential course participants, and enabled online and in-person attendance; although in-person participation was capped at 15 people per course.

Demand for the courses was high and all were extremely well attended (Figure 1). The post-activity interviews (described above) indicated that further courses would be welcomed. These interviews also indicated that the courses enabled people to forge connections (especially those who attended in-person) and that they had subsequently reached out to other course attendees for help.

Importantly, courses should aim to facilitate end-to-end skill enhancement that is, from beginner to advanced. Much of the focus in these and other courses has been on the use of packages, but an advanced stock assessment scientist should also have training in, for example, coding and version control practices.

5 | Creating Tools and Resources

All stock assessment scientists should also have an awareness of which packages are available and which to use, and when a bespoke package is the only or best option. A previous review of all assessments undertaken in Australia (Dichmont et al. 2016) noted there was no central repository for stock assessment packages for Australian stock assessment scientists. As a result, a website (https://toolbox.frdc.com.au/) was developed that collates available stock assessment packages (from data-limited to data-rich) to provide stock assessment scientists with a single platform that summarises the features of the available packages in a consistent manner (Dichmont et al. 2021). Updated every 6 months, the website also highlights current state-of-the-art packages, and those that are no longer supported or have been superseded. This toolbox broadens that of the NOAA's Fisheries Integrated Toolbox (https://noaa-fisheries-integrated-toolbox.github.io/) reflecting NOAA's package use. Links to Australian stock assessment reports are also provided on the website, and the list of these was expanded with inputs from the community list we developed.

Of importance is that the Toolbox provides informed expert advice on which package is best for various types of assessment (e.g., from length-, age- or catch-only to integrated assessments), since many assessment types are common across multiple packages. The repository and guidance enable assessment scientists to be aware of, and navigate across, the available packages.

Furthermore, adding stock assessment reports to the web site highlighted that Australia does not act as a norm; prioritise making assessment reports/outcomes consistently and publicly available in a central location. This responsibility is assigned to each jurisdiction, but that process is less effective at providing transparent and easily accessible stock assessment reports. Consequently, stakeholders and scientists often struggle to find information on stock assessments that have been conducted for their specific species or similar fisheries of interest.

6 | Learning From Play

Soon after the training courses, we provided a 'Game' where the stock assessment scientists could undertake a stock assessment of a simulated data set, where the actual population information (such as stock size) was known by those who developed the game, but not by those who participated. We used our email list to advertise the Game. Contact thereafter was only with those that asked to be included. Details can be found in Punt et al. (2025) and summarised in the Supporting Information.

The Game provided a relatively rare opportunity for consequence-free learning, and we highlighted that the emphasis was on providing a fun and enjoyable learning activity. We were interested in how participants organised themselves and whether their participation in our training courses had affected their behaviour (either positively or negatively). For example, did meeting other stock assessment scientists during the courses mean that analysts would collaborate beyond their organisation-specific teams during the Game? Did the courses enhance their skill and ability to undertake a complex assessment? A particular focus on the Game was to identify major difficulties experienced when conducting an assessment, and hence future training needs.

The Game involved generating a dataset using a simulation model that represented a stock distributed over 12 regions and harvested by three fishing fleets. The simulation model differed from the standard specification for a stock assessment by including spatial structure, time-varying selectivity for some fleets, and changes over time in expected recruitment due to the effects of an environmental driver. The participants self-organised into six mainly organisation-based groups. Groups were requested to report estimates of current biomass, current depletion and to provide advice regarding the possibility of local depletion. To encourage participation, a prize (a copy of Thorson and Kristensen 2024) was promised to the group that provided the 'best' (most accurate) estimate of current spawning biomass (thus rewarding the outcome, rather than the process that was undertaken to achieve it).

While there were no restrictions on how groups self-organised, most organisations undertook their assessment in-house, possibly because the understanding of participants was that this was to be a fun competition between existing groups. Also, at least two organisations had recruited scientists new to assessment who had attended the courses, and it was felt they would benefit from participating in the Game before undertaking an actual assessment.

Most groups used SS (Methot and Wetzel 2013), but it is unclear whether they used this package due to the courses or because they had used it before. Post-activities phone interviews showed that the courses helped some of the stock assessment scientists to use these packages and that the Game was a driver to apply their newly learnt skills.

Most of the estimates of current spawning biomass from the groups that partook in the 'Game' were too large, while depletion was estimated to be too low (i.e., the stock had been less heavily exploited than was estimated). None of the groups identified that the pre-specified value for natural mortality, M, was incorrect. Post 'Game' re-runs of the 'best' models using the correct value for M (but with no other changes to the model specifications) yielded better estimates of depletion but surprisingly poorer estimates of spawning biomass in absolute terms. The results highlighted the need for additional training in spatial population dynamics modelling, use of methods for pre-processing monitoring data to select appropriate fleet and population structures, as well as the use of agreed methods to provide initial values for the parameter determining the rate of natural mortality natural mortality, M (Punt et al. 2025). A course on the use of the spatial features of SS was developed and provided in response to this finding. This course was well attended (Figure 1).

It is important to note that the performance of the assessment teams was not solely dependent on training. As demonstrated by Deroba et al. (2015) and this study, even experts can struggle with complex, low-information data. While the assessors adhered to best practices for model use, they faced challenges in determining the spatial structure of the stock and its biological aspects—balancing these factors while ensuring model convergence proved difficult. In addition, the lack of standardised tools for pre-assessment data analysis contributed to the diverse methodologies employed across teams.

The project team was surprised by the extent to which participants were engaged and how seriously they took the Game. We did not anticipate the perceived 'corporate risk' associated with groups submitting reports for scrutiny. In retrospect, it may have been preferable not to have offered a prize because, rather than this having been perceived as an incentive to participate (as was intended) for some, the promise of a prize invoked the unintended consequence that groups viewed the Game as having a very competitive focus whereby people could be unfavourably compared.

Due to privacy constraints, the initial Game results were anonymised during feedback to the participants. It was only when the Game journal paper was written (Punt et al. 2025), with all participants as authors, that openness and transparency became possible. This enhancement of the learning experience allowed groups to learn from each other by comparing their different approaches in more detail.

Based on our experiences from the implementation of the Game, we believe that any future Game should commence with an in-person meeting with the game developers so that participants can more freely self-organise (especially across organisations) and more readily ask initial questions. In addition, inter-organisation competition and perceived risk in future 'Games' could be mitigated by randomly assigning participants to groups

and additional de-identification during the group discussion of results and outcomes.

As an overall summary of participation, of the original email list of 179 scientists, 96 (54%) scientists did not participate in any of the abovementioned events, while 33 (18.5%), 11 (6.2%), 21 (11.8%), 13 (7%) and 4 (2.5%) scientists attended one, two, three, four or all five events (being interviews, SS3-, SAC-, SS3 spatial courses, the Game, interviews) respectively.

7 | Discussion

The aim of this study was not only to assess the extent and drivers of collaboration in Australian stock assessment, but to be a driver of change itself by testing various approaches to improve collaboration as well as upskill the current cohort of stock assessment scientists. Two key needs emerged: further training and the development of a Community of Practice (CoP).

7.1 | SS3 Spatial Courses

Similar to other studies and theoretical texts cited below, this study highlighted the importance of training. Effective training and development programmes in organisations have been shown to be highly beneficial in numerous ways, including building individual and organisational capability, enhancing retention of talented individuals (Jones and Wright 1992) and conferring competitive advantages (Meyer and Allen 1997). The focus of training to develop and enhance skills for any highly skilled profession (including fisheries stock assessment) is important in that it can then facilitate organisational change and increase productivity (Valle et al. 2000). Training not only increases the expertise of individuals, but there is evidence that continuous learning has a positive impact on employee productivity (Noe 2016). Training and development are essential for all levels of employees, since skills erode over time, eventually becoming obsolete and hence in need of improvement.

Berkson et al. (2009) described three causes for the shortage of stock assessment scientists in the USA: (a) not enough university faculty to teach or supervise students, (b) not enough courses essential to prepare potential stock assessment scientists, and (c) the quantitative skills of graduate students from fisheries programs not being sufficient for assessment positions. This study does not address these pipeline issues or solutions, but rather undertakes these activities in the work force and accepts that there are varied skill sets and backgrounds. By sharing and training together, this can equalise the expertise. In reality, programmes such as that undertaken in Berkson et al. (2009) and identified in ICES (2021) are also required.

However, in addition to the benefits of training outlined above, our results show that training across organisations and groups is essential to building long-term collaborations and relationships. This means that future courses should involve both in-person and online components, and be a shared activity.

Future training should follow career pipelines and the community's needs, as well as cater to all skill levels, and could be a focus for a future CoP. Our training was focused on stock assessment packages, as these were an identified priority for Australian stock assessment scientists. However, we acknowledge that education on a broader understanding of population modelling and advanced parameter estimation may be as or more valuable for expanding stock assessment capacity than training on software packages.

One training direction is to ensure that stock assessment best practices (e.g., Cope 2024; Punt 2023) are known, understood and followed. Courses should therefore focus on: the basic assumptions behind an assessment; how to analyse the data and assemble these for the assessment method to be used; model formulations including sex, space and time; formulation of population processes such as growth, natural mortality, and selectivity; which parameters should be time-varying and how to implement this in the model; data weighting and model fitting; diagnostics; how to describe uncertainty; and finally the use of version control or similar data science methods.

In the Australian context, given that few stock assessment scientists are trained within the Australian university system, courses starting with stock assessment terminology and basic assessment principles are essential to scientists coming from allied fields. In common with many technical fields, stock assessment and fisheries management are 'terminology rich' (Wetzel et al. 2024), and this can be a block to learning methods as highlighted during the interviews (Pascoe et al. 2025a). In contrast, experienced stock assessment scientists are more likely to need training in new approaches. For example, SS is being transitioned to The Fisheries Integrated Modelling System (FIMS—https://www.fisheries.noaa.gov/national/population-assessments/fisheries-integrated-modeling-system), which is being coded in R and TMB. When this transition is complete, it is expected that Australia, with its large investment in SS, will need courses on FIMS and TMB (and the R-based version of TMB, RTMB).

The above speaks to the need for education—an understanding of population modelling and parameter estimation—as a foundation, but more to having a larger community come to use a flexible modelling framework that provides wider testing, features and overall understanding. If that framework can include a large variety of different combinations of data types, then we can work toward a unified modelling framework that does not diminish creativity and need, but does improve comprehension, development, and communication. The fact that SS (a tool that has developed over decades of user input, testing and application) will eventually be overtaken by FIMS does not diminish the community using it now or who will transition together to the newer format. If the focus is on community rather than the model, the community can transition and grow together in ability and capacity.

The use of play, being a consequence-free activity such as the Game, highlighted an immediate training need. This need was met by a course on how to implement spatial structure in SS3 assessments, which was provided soon after the Game. This

process showed that training programs must be flexible and evidence based.

Given the plethora of stock assessment packages, some guidance is provided on the Toolbox web site as to which packages are best in their classes, and which assessment types are best avoided. Training also needs to highlight when to use specific methods and which tools are best for specific circumstances. This can be done directly or through learning how to use the FishPath Tool (https://fishpath.org/) that guides analysts through the model choice process (Dowling et al. 2023).

Ultimately, the outcome of training should be that stock assessment scientists know when to develop a bespoke model (and have the necessary skills and support to do so); or, if a package can be used, understand and can make an informed decision about which package is best given the data (based on an awareness of the range of available packages). However, simply learning about a package is insufficient. It is important that the underlying assumptions and principles are well understood. The training courses on the SAC Tool demonstrated that a continuum of assessment methods all underpinned by the same integrated modelling framework (e.g., SS in this case) is much more overt at highlighting the basic assumptions being made as one moves from data-poor to data-rich methods than a series of individual packages, each based on one method.

Training and courses need to be supportive so that mistakes are encouraged as a way of learning and be inclusive by being open (i.e., beyond the organisation that is leading the course). The disadvantages of making jurisdiction-based courses accessible to the entire community are that this requires more coordination and is harder on the trainer, and that it is easier for participants to have more confidential discussions about their management systems or issues within the organisation when the course is conducted in-house. However, the interviews showed that the benefits of shared courses outweighed these potential costs. 'Open' training was also found to foster long-term collaborations, especially for the in-person attendees.

Developing a culture within an organisation of continuous learning and development is essential—irrespective of whether this is focused on 'hard skills' such as stock assessment methods or the 'softer skills' of turning one's work into peer-reviewed publications and presenting assessments to stakeholders. These are all components that enhance a scientist's career. This can be achieved through various means, including specialised courses or institutional support for scientists pursuing advanced degrees, such as enabling part-time study. Stock assessments are notoriously difficult to publish in journals. The network analyses showed that many stock assessment scientists mainly publish their work as reports. Yet, journal papers remain a key and respected form of communication among scientists, and not all Australian assessment reports are easily accessible (or even online). The network analyses highlighted that there are scientists with the skills to identify and then publish novel aspects of stock assessments. These scientists could mentor others who struggle in this regard. Training in publishing assessment results in journals should be a cross-institutional endeavour, given the strong publication record of a few groups/organisations in Australia. However, the incentive to publish is not always clear. For example, an organisation may not consider citation statistics in promotion cases; and the time, capacity, and opportunities to invest in skills may not be seen as worthwhile and part of core duties of the organisation or the scientist. Thus, changes at both the scientist and organisational level may be required to create the environment and incentives for publishing.

Clearly Australia will continue to have a diversity of team sizes and skills, and priorities among jurisdictions. This is not likely unique in the world. Emphasis in training programs for stock assessment should therefore focus on (a) connecting teams in an effective and sharing community, (b) maintaining a pipeline of skilled assessment scientists who can grow their skills and contribute nationally, and internationally and (c) reducing reliance on a few key scientists, which means that the available set of teachers needs to be expanded through "training the trainers".

7.2 | Community of Practice

Although coursework training is crucial, ongoing discussions, support and sharing within a community, and simulation games are also needed so that stock assessment scientists can continually build and grow skills through various activities. This means that sharing through a CoP, for example, would lead to a network of experts that will allow stock assessment scientists to resolve issues as they arise by asking colleagues for help. The CoP should also facilitate sharing relevant topics, papers or coming events. From the interviews, there was also a call for an annual in-person workshop with a specific stated objective.

Best practice in stock assessment has been a major discussion point within the international stock assessment community, facilitated by, for example, the Center for the Advancement of Population Assessment Methodology (CAPAM; Maunder et al. 2025). CAPAM is an international CoP established to determine 'good practice for developing robust fishery models' and provides educational and training opportunities. It resulted in a series of workshops and publications on good practices on specific topics, such as data weighting (Maunder et al. 2017), spatial structure (Cadrin et al. 2023) and natural mortality (Hamel et al. 2023), and most recently on stock assessment good practices in general (Maunder et al. 2025). CAPAM was founded in 2012 and, to date, has run 12 topic-based workshops (Maunder et al. 2025). Another example is the ICES Working Group on fish stock assessment, which has brought together international experts to develop guides on common topics such as reference points and harvest control rules (ICES 2023a), management procedures and assessment diagnostics, uncertainty and evaluation (ICES 2023b) and data limited approaches (ICES 2013).

Although Australians have engaged in the CAPAM workshops, especially those that were conducted in hybrid format (e.g., Hamel et al. 2023), international travel is difficult for several Australian organisations, so only a few Australian attendees have been able to participate in the in-person sessions at a time

(and most likely from the same organisations each workshop). CAPAM is a good model for an Australian CoP, but for one that initially focuses inward to address Australian needs.

The network analyses highlighted the risks of losing key people and the dangers of insularity. We showed that five people and one organisation were largely key to communication within the Australian stock assessment community. There are risks in both areas, as key scientists could leave or retire, and an organisation may choose to exit the field or reduce investment and staff. The CoP will allow a broader community to access existing key scientists, but also allow other scientists to take or share these key roles. There is another insularity risk in that knowledge brokers may promote outdated practices. More formal education and continuing education can offer a powerful supplement to reliance on 'thought leaders'. Also, a CoP is advantageous in this context as it does not promote one method or practice and enables the community to hear and learn from a range of experts.

The Game showed that providing scientists with a safe space to interact, learn, and take risks is valued in fields where scientific results have an immediate impact (on the public or stakeholders). Offering new and experienced scientists opportunities to enhance and test their skills in a team environment is therefore beneficial not only for the stock assessment scientists but also to identify common elements that are done well and areas for improvement. The Game or something similar could be developed as part of the CoP program every few years.

8 | Conclusion

Based on our interviews, the combination of the various activities outlined in this paper was more beneficial to increase collaboration and knowledge than only undertaking one such activity; although the sequence of activities arguably matters. Undertaking the Game after the courses allowed scientists to apply and take risks with their newly acquired skills without consequences. This also enabled the immediate application and consolidation of new skills from courses, which might otherwise have been lost through a lack of immediate real-world opportunities or general disuse. Further, there were multiple examples of scientists explicitly stating that they had applied the skills they had developed to stock assessments for which they were responsible, as a result of the capability and confidence developed from participating in both the courses and the Game. The Game allowed the team to review assessment expertise and needs, which resulted in a subsequent spatial SS course. Adding a spatial SS course after the Game can be avoided in future by adding an extra day for this component to any subsequent SS courses.

The study highlighted an ongoing need for a more formalised and collaborative community, such as through a CoP, which would enhance skills. How the CoP is designed is important as there is a lack of sustained funding to establish and maintain an Australian CoP. Although costs would mean that the CoP would be mainly based online, the survey respondents clearly articulated the importance of face-to-face connections. This means that future courses should involve in-person and online components, and an annual in-person workshop with a specific stated objective is essential. However, it is necessary to also consider the costs of not developing a CoP or if it fails over time.

Despite CAPAM being seen as an important CoP by the stock assessment community (Maunder et al. 2025), it is not accessible to most of the Australian stock assessment community, meaning that something similar in Australia would need ongoing support from each/most of the organisations and ultimately will need to have secure funding. More generally, prioritising the ongoing development of, and support for, Australian stock assessment scientists is necessary, but it is a shared responsibility (both financial and in-kind) of all relevant organisations and agencies.

This study does not account for other factors that influence individual and organisational well-being and productivity. For example, optimising investments and processes related to data quality/quantity and assessment frequency could help free up assessment resources. Streamlining and integrating data protocols would free up more time for stock assessment modelling and may improve system performance. Exploring these factors in future research would be a valuable next step.

We conclude with the following list of recommendations for improving the stock assessment community that are relevant to Australia and likely many other jurisdictions. We feel that implementing these will optimise the chance of feeding the pipeline and building a more capable, collegiate community, and promoting the well-being and collaboration of stock assessment scientists.

9 | Recommendations

- Use training courses as an opportunity for scientists to connect. This helps people be more comfortable asking advice from those outside their organisation/team. Training needs should be seen as on-going, especially as assessments move to TMB and RTMB and the desire to add climate and ecosystem drivers to models increases.
- Allowing stock assessment scientists to participate in a simulation 'Game' that tests and expands their knowledge every few years is essential. Taking from the learning mentioned in this paper, ensuring a safe environment with only healthy levels of competition is important. Reporting back in detail on results is essential.
- Create a CoP, which is a safe space for scientists to interact. For this CoP to be successful, it needs to involve sharing and updating best practices, using common stock assessment packages, sharing training and training load, and knowing when to use bespoke models.
- Conduct shared peer reviews as they are an essential component of ensuring stock assessment quality (Brown et al. 2020). The CoP can be used to expand the available pool and quality of peer reviewers.
- Encourage collaboration to create best practices and methods that are robust to regional situations and robust

to different input and output needs,; to give them broader appeal.

- Use network analyses (or similar methods) to (a) define knowledge brokers who are crucial to any CoP, (b) identify new recruits to the knowledge broker pool and (c) highlight risks with respect to loss of key scientists. Ensure these groups, especially the knowledge brokers, stay up to date so that they do not inadvertently promote outdated practices.
- See investment in the training and development of stock assessment staff as core to organisational success.
- Develop succession plans as an essential component of providing for the supply chain.
- Develop under- and post-graduate studies that aim to generate the next generation of modellers and stock assessment scientists following other similar programmes and recommendations (U.S. Dept. of Commerce 2008). As a first step, a census of available university courses would be a good start (e.g., ICES 2021) as well as developing dedicated workshops to expose quantitative students to stock assessment (e.g., Berkson et al. (2009)).
- Training and educational needs should consider both theoretical and implementation details.
- Expand any stock assessment-based CoPs so that stock assessment scientists are ready to modify their skills base and/or interact with scientists from, for example, ecosystem and climate (e.g., (Fulton et al. 2024), economic (Dichmont et al. 2010), social (Barclay et al. 2023) and multi-species (Plagányi et al. 2014)) modelling.
- Develop best practice methods and tools for pre-assessment data analysis.
- Prioritise making assessment reports and outcomes consistently and publicly available in a central location.
- Provide mentorship so that assessment scientists can publish novel aspects of stock assessments.
- Include publication in peer reviewed journals as a key part of the scientist's core business.

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Data Availability Statement

Much of the underlying data on this paper are published and referenced in this paper. All the underlying data is subject to ethics approval and cannot be released in a form where people can be identified. Given the small size of the assessment population, no data are provided online. The corresponding author can be approached if any further information is needed.

Endnotes

[1] For privacy reasons, names have been redacted.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure S1:** faf70018-sup-0001-FigureS1.docx.