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Research Priorities for Coastal Geoscience and Engineering: A Collaborative Exercise in Priority Setting From Australia

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We present the result of a collaborative priority setting exercise to identify emerging issues and priorities in coastal geoscience and engineering (CGE). We use a ranking process to quantify the criticality of each priority from the perspective of Australian CGE researchers and practitioners. 74 activities were identified across seven categories: Data Collection and Collation, Coastal Dynamics and Processes, Modelling, Engineering Solutions, Coastal Hazards and Climate Change, Communication and Collaboration, and Infrastructure, Innovation, and Funding. We found consistent and unanimous support for the vast majority of priorities identified by the CGE community, with 91% of priorities being allocated a score of $\geq$ 3 out of 5 (i.e., above average levels of support) by $\geq$ 75% of respondents. Data Collection and Collation priorities received the highest average score, significantly higher than four of the other six categories, with Coastal Hazards and Climate Change the second ranked category and Engineering Solutions the lowest scoring category. Of the 74 priorities identified, 11 received unified and strong support across the CGE community and indicate a critical need for: additional coastal data collection including topographic and bathymetric, hydrodynamic, oceanographic, and remotely sensed data; improved data compilation and access; improved understanding of extreme events and the quantification of future impacts of climate change on nearshore dynamics and coastal development; enhanced quantification of shoreline change and coastal inundation processes; and, additional funding to support CGE research and applications to mitigate and manage coastal hazards. The outcomes of this priority setting exercise can be applied to guide policy development and decision-making in Australia and jurisdictions elsewhere. Further, the research and application needs identified here will contribute to addressing key practical challenges identified at a national level. CGE research plays a critical role in identifying and enabling social, environmental, and economic benefits through the proactive management of coastal hazard impacts and informed planning to mitigate

the potential impacts of growing coastal risk, particularly in a changing climate. The prevalence and commonalities of the challenges faced by coastal communities globally due to increasing pressures from coastal hazards in a changing climate suggest that our findings will be applicable to other settings.

INTRODUCTION

Coastal communities, infrastructure, and livelihoods around the world are being affected by the impacts of coastal processes, such as erosion, flooding, and severe storms (Ranasinghe, 2016; World Oceans Review, 2017; Toimil et al., 2020). The scale and frequency of these impacts, enhanced by a changing climate, requires a coordinated effort to prioritise, plan, and implement adaptation measures. Horizon scanning and collaborative priority setting exercises have been widely used to identify emerging issues and priorities in science, and to determine their relative importance from a researcher and practitioner perspective (e.g., Sutherland et al., 2011; Rudd and Lawton, 2013; Rudd, 2014; Nichols et al., 2019; Wisz et al., 2020). Within the discipline areas of marine and coastal science, several studies have been undertaken that have identified priority research questions and topics. Most of these studies had a global focus (e.g., Rudd and Lawton, 2013; Rudd, 2014, 2017; Wisz et al., 2020), which resulted in broad research priorities that cover ocean research as a whole (e.g., Fissel et al., 2012; Rudd, 2014, 2017; Lundquist et al., 2016). National-scale studies, similarly broad in scope, have been undertaken in some jurisdictions, such as that by Jarvis and Young (2019), who identified the ten highest priority research questions across each of nine thematic areas for the future of marine science in New Zealand. Whilst a number of discipline specific priority setting studies have been carried out (e.g., Rees et al., 2013; Rudd and Lawton, 2013), specific actionable and detailed priorities that are required to inform and ultimately address the impacts facing coastal communities and infrastructure have yet to be identified.

Australia's coastline is the sixth largest in the world, spanning multiple climate regions and hosting a vast diversity of coastal environments including more than 14,000 beaches (Short, 2006; Clark and Johnston, 2017). With more than 85% of the Australian population living within 50km of the coastline, these coastal environments are subject to increasing pressures from catchment land use, settlement, and infrastructure development, which often extends across the coastal zone and, in some cases, to the shelf edge (Clark and Johnston, 2017). The majority of these pressures are directly or indirectly related to human activities, and Australia's reliance on its coast for amenity and resources means that much of the coast has been modified (Clark and Johnston, 2017; Ware, 2017; Thom, 2020). Australia's coast is also particularly vulnerable to the effects of climate change with increases in sea level, changes in wave climate and storminess, and ocean warming all expected to have significant and, in some areas, above global average impacts in Australia (Department of Climate Change, 2009; Gurran et al., 2011; Ranasinghe, 2016;
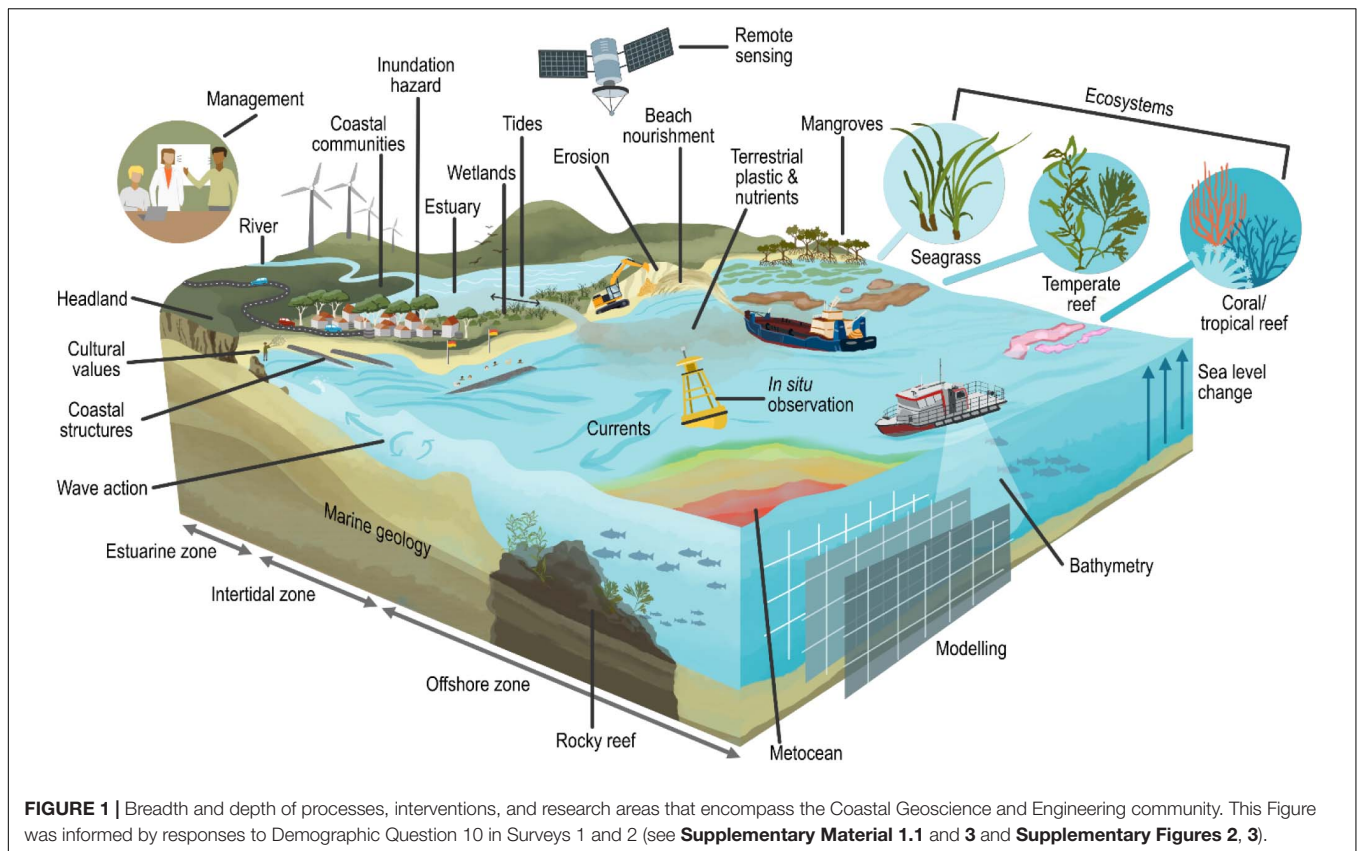
IPCC, 2019). Indeed, these impacts are beginning to emerge (e.g., Harley et al., 2017; Hanslow et al., 2019; Hague et al., 2020) and are forecast to escalate in coming decades (e.g., Kinsela et al., 2017; Hanslow et al., 2018; Holper et al., 2018; Seashore Engineering, 2019; Ware et al., 2020). Consequently, it is essential to identify the key research priorities that will allow societies to address these major global challenges.

Coastal geoscience and engineering (CGE) is a broad research discipline that covers the physical processes and environmental changes that occur along the land-sea (coastal) interface. It encompasses both researchers (basic and applied) and practitioners that specialise in coastal oceanography, sedimentary geology, geomorphology, geochemistry, sedimentology, and engineering, as well as coastal zone managers and communicators, who have important roles in making decisions that balance the needs of communities, industry, and the natural environment (**Figure 1**; Vila-Concejo et al., 2018). Greenslade et al. (2020) recently identified 15 research priorities for wind wave research in Australia, however, their analysis focussed on one aspect of oceanography and does not represent the full breadth of CGE research. Here, we present the results of a collaborative research priority setting exercise for the CGE discipline within Australia. Whilst we focussed on Australian settings, the diversity of Australia's coastal environments and the large-scale physical drivers of the challenges mean that many of the priorities identified here likely have broader global relevance.

The objective of this study was to compile a list of priority research activities and research-enabling activities (here after referred to collectively as 'priorities') that could be used to inform the direction of future CGE research. In this study, we also aimed to capture the diverse disciplines, sectors, and experiences within the Australian CGE community to identify the relative significance of the priorities. The identification of these priorities and of those that are considered most pressing will provide insights for coastal policy and management, and can support Australia, along with many other countries, in the actions they take during the United Nations Decade of Ocean Science for Sustainable Development (2021-2030) (Ryabinin et al., 2019).

METHODS

We used a four-part approach, based on the methodology developed by Sutherland et al. (2011), to identify and rank the priorities. This method was chosen as it is an iterative method that engages the community of interest throughout the process, is democratic, and has previously been used to identify research

FIGURE 1 | Breadth and depth of processes, interventions, and research areas that encompass the Coastal Geoscience and Engineering community. This Figure was informed by responses to Demographic Question 10 in Surveys 1 and 2 (see **Supplementary Material 1.1** and **3** and **Supplementary Figures 2**, **3**).

priorities in a range of other disciplines including within marine science (e.g., Fissel et al., 2012; Greenslade et al., 2020; among many others). A summary of the process is presented in **Figure 2**.

Stage 1: Community Nomination of Initial Priority Activities

We first surveyed the CGE community in Australia to identify a long-list of priority activities and infrastructure needs. Invitations were emailed to a list of participants generated from a search of the academic and grey literature (e.g., technical and government reports), online listings of professional staff from relevant organisations, as well as from the professional networks of the project team ($n_{invitations}$ = 282). In addition, the survey was promoted via national and international mailing lists to maximise the reach of the project.

Survey participants were asked to describe up to 10 priority activities that they thought the Australian CGE community should address over the next 5–10 years. Responses were requested to meet the following criteria: (i) that the scope of the activity was anything related to coastal geoscience and engineering; and (ii) that the level of effort for each activity should be achievable by 1 or 2 researchers within a few years. In addition, participants were asked if the infrastructure and equipment (e.g., observing platforms, information technology infrastructure, specific sensors) existed to address these challenges. If the participant felt this infrastructure and equipment did not exist, they were given an opportunity to
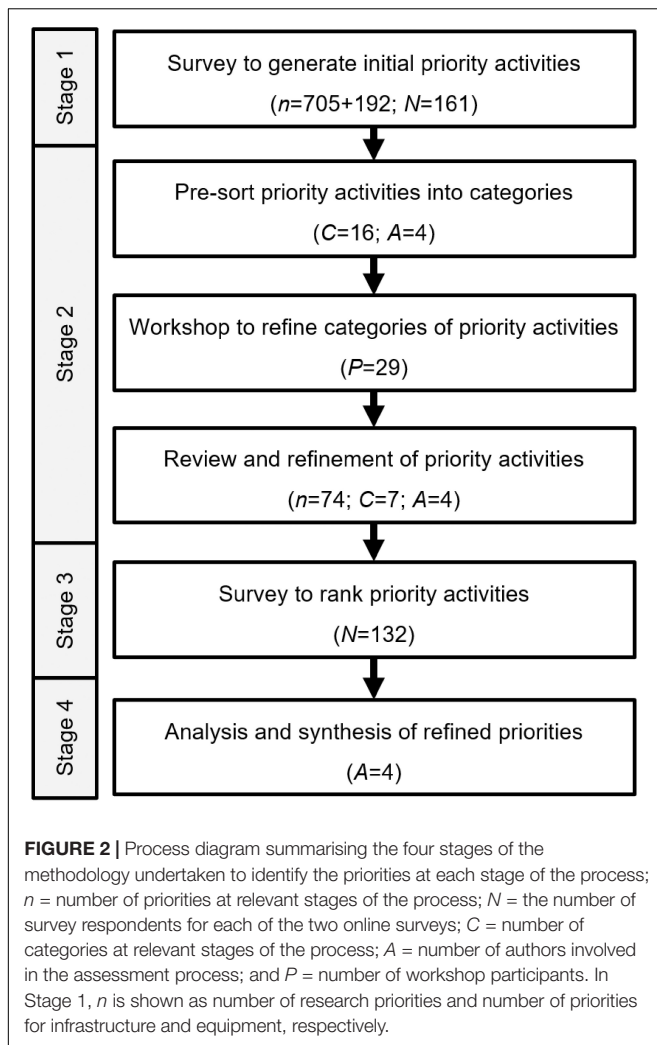
provide up to 5 priorities for new infrastructure and equipment (see **Supplementary Material A.2** for survey questions).

To understand the demographics, professional area, and career stage of the participants, a series of demographic questions were included in the survey (see **Supplementary Material 1.1**). Participants could also elect to provide contact details so that they could be included in future surveys/workshops and be informed of the outcomes of the project. The demographic and survey results were not linked to individuals' contact data and therefore individual responses and demographics cannot be connected to individual respondents. This initial survey and the subsequent survey (Stage 3) were both completed online via the software LimeSurvey.

The initial online survey was launched on 18 October 2019 and was open until 5 November 2019 with two email reminders sent after the first invitation to participate. A total of 161 participants completed the full survey and 121 participants elected to provide their contact details. Incomplete surveys were removed from further analysis. This resulted in the submission of 705 priorities and 192 infrastructure and equipment responses.

Stage 2: Categorising and Synthesising Priority Activities (Workshop and Priority Review)

The submissions from the initial survey (Stage 1) were first reviewed to remove invalid responses (e.g., "?", "no," and "N/A"). The responses were then divided into 16 initial categories, which

FIGURE 2 | Process diagram summarising the four stages of the methodology undertaken to identify the priorities at each stage of the process; n = number of priorities at relevant stages of the process; N = the number of survey respondents for each of the two online surveys; C = number of categories at relevant stages of the process; A = number of authors involved in the assessment process; and P = number of workshop participants. In Stage 1, n is shown as number of research priorities and number of priorities for infrastructure and equipment, respectively.

were developed to encapsulate the full breadth of the responses that remained. Each author allocated 50% of the responses to one of these 16 categories and every response was assessed by two of the four authors.

A workshop was conducted on Tuesday 12 November 2019 to coincide with the 2nd International Workshop on Waves, Storm Surges and Coastal Hazards in Melbourne[1]. Invitations were emailed to all Stage 1 participants who had provided contact details. The workshop was also advertised at the conference opening session. During the workshop, participants were grouped into teams of two or three participants and allocated one or two of the 16 categories (depending on the number of responses allocated to each category). Participants were provided with a randomised list of all responses in their allocated category(s) along with a word cloud of the most frequently used words in the responses. The participants were asked to edit, clarify, and merge research activities from the long-list of responses. From these refined categories, participants were then asked to generate a short-list of priorities and

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[1] https://conference.eng.unimelb.edu.au/waves/

to conduct a preliminary prioritisation of these priorities. A total of 29 participants attended the workshop including the manuscript authors.

Following the workshop, we reviewed the short-lists against the full list of all responses to ensure that all responses had been captured by the refined priority activities developed in the workshop. Cross-referencing, editing, and refining was then undertaken to remove duplicate research activities that appeared in multiple category short-lists. Finally, the 16 initial categories were consolidated into 7 categories to reduce duplication. This resulted in a short list of 74 priorities across the 7 categories (**Table 1**).

Stage 3: Community Scoring of the Priority Activities

The refined list of priorities was returned to the CGE community via a second online survey in order to rank the priorities and assemble a final list of priorities. The survey was circulated in the same manner as the Stage 1 survey with additional invitations sent to participants who had provided their contact details in the first survey ($n_{invitations}$ = 313). The survey commenced on 17 June 2020 and closed on 10 July 2020. A total of 132 participants completed the full survey and 108 participants elected to provide their contact details.

Participants were presented with the short-list of priorities, which were grouped into the 7 categories. Each category was presented in turn with the list of priorities within each category presented in a random order. Categories with more than 10 priorities were presented in two halves. Participants were asked to rank each priority from 1 (somewhat relevant) to 5 (critical) with an option to mark any priorities that they did not think should be listed as a priority with "N/A." Participants could also select "Unsure." Within each category, and at the end of the survey, participants could enter any additional activities that were notably absent that they thought should be listed. Responses to these open questions were requested to meet the same criteria as those detailed in Stage 1 (see **Supplementary Material 1.3** for survey questions). As per Stage 1, survey participants were asked a series of demographic questions (see **Supplementary Material 1.1**) and incomplete survey responses were removed from further analysis. The demographic results from Stage 3 are presented in **Box 1** and **Figure 3**.

Stage 4: Analysis of Survey Responses

The survey responses for each priority were plotted in stacked bar graphs to visualise the distribution of respondent scores between individual priorities and between the seven categories (see Section "RESULTS"). Both a mean score ($\bar{R}$) and a weighted mean score ($\bar{R}_w$) were calculated for each priority to summarise the collective respondent scores (N = 132). The mean score is simply the mean of participant scores (0–5) for each priority, where an "N/A" response represents a 0 score (respondent did not think it is a priority) with "Unsure" responses excluded from calculations. The standard deviation was also calculated for each priority along with the mean of mean scores (and envelope of standard deviation) for each category and plotted on the bar

TABLE 1 | The priority research and enabling activities (*n* = 74) synthesised from the 705 research activities and 192 infrastructure and equipment priorities that were nominated by respondents from the CGE research and stakeholder community (*N* = 161).

Data Collection and Collation

DAT1	Obtain novel measurements of waves, water levels, and currents during extreme conditions (e.g., during tropical cyclones) and explore extreme tails of event and impact occurrence
DAT2	Increase spatial resolution, coverage, and frequency of collection of hydrodynamic and oceanographic data in coastal environments, including (but not limited to): waves, currents, water level, ground water, and ocean chemistry
DAT3	Increase spatial resolution, coverage, and frequency of collection of remotely sensed coastal, estuarine, and ocean environmental data, including (but not limited to): satellite data, coastal imaging data, drones, LiDAR, aerial imagery, aerial survey, and photogrammetry
DAT4	Increase spatial resolution, coverage, and frequency of collection of topographic and bathymetric survey data
DAT5	Develop and deploy standardised collation, indexing, storage, and management of coastal data (process, monitoring, modelling, and infrastructure) in an open-access environment to enable data integration and 'big data' analyses
DAT6	Develop and adapt new or emerging data science analysis techniques (including remote sensing, machine learning, artificial intelligence, and probabilistic methods) and apply these to coastal research and management problems
DAT7	Increase research and development of low cost options for coastal monitoring
DAT8	Develop consistent guidelines for the development of coastal monitoring programmes that generate nationally comparative data from different Australian coastal settings
DAT9	Undertake system scale monitoring of coastal and estuarine environments to quantify interconnectivity and interdependence of ecosystems and their adaptation to climate change
DAT10	Conduct national-scale mapping and analysis of geological, historical, and potential future coastal change (extreme events and long-term) using a combination of existing and remote sensing data
DAT11	Identify archetypal coastal systems and environments to establish a national coastal monitoring network
DAT12	Increase data collection through underutilised data sources (including community and indigenous knowledge)
DAT13	Increase data collection on human usage and values of coastal environments

Coastal Dynamics and Processes

DYN1	Quantify underlying and fluctuating shoreline change due to sediment budget imbalances, sea-level rise, and erosion-recovery cycles over a range of spatial and temporal scales
DYN2	Quantify with greater accuracy the nearshore hydrodynamic processes that contribute to coastal inundation including wave runup, wave setup, dune overtopping, and estuarine inundation
DYN3	Characterise probability distributions for extreme events including extreme water levels, waves, and coastal erosion as well as joint probability assessments with a particular focus on the distribution tails
DYN4	Develop early warning systems for coastal wave hazards, erosion, and inundation and their impacts in different Australian coastal settings
DYN5	Map the behaviour of tidal inlets (e.g., rivers, estuaries, ICOLLs, and creeks) to understand and enable the prediction of inlet morphodynamics with respect to coastal processes (waves, water levels, flooding, and sediment availability)
DYN6	Quantify with greater accuracy the net rates of sediment transport in the cross-shore and longshore
DYN7	Develop strategies to maximise coastal and estuarine ecosystem health in urban environments
DYN8	Characterise, spatially map, and model the geomorphology, sediment dynamics, and sediment budgets (including the palaeo-environmental and geotechnical character) of coastal sediment compartments and their connectivity
DYN9	Develop the fundamental theory of the physics that govern hydrodynamic, sediment transport, and shoreline evolution processes
DYN10	Quantify with greater accuracy short and long (infragravity) wave processes and their impact on sediment transport and shoreline change in different Australian coastal settings
DYN11	Develop and implement a national scheme, standard, and baseline to assess health of coastal ecosystems (including water quality) for a range of ecosystem types
DYN12	Quantify the impacts of human activities, transportation (e.g., 4WDing on beaches), and recreation (e.g., boat wakes) on overall sediment dynamics and coastal morphology
DYN13	Quantify with greater accuracy the risk of tsunamis and their impacts (including palaeotsunami and submarine landslide tsunami)

Modelling

MOD1	Quantify the impact of future wave climate scenarios on coastal sediment transport and shoreline dynamics
MOD2	Develop national and regional scale coastal and estuarine hydrodynamic and morphodynamic hindcast and forecast models for the Australian coastline that have publicly accessible data streams
MOD3	Develop a national and regional scale metocean hindcast and forecast model for the Australian coastline that has publically accessible data streams
MOD4	Develop a framework and guidance for the application of numerical, probabilistic, and statistical models to assess climate change impacts in different Australian coastal settings
MOD5	Improve the spatial and temporal resolution and accuracy of coupled atmospheric-ocean-wave models in different Australian coastal settings
MOD6	Refine existing numerical coastal process and dynamics models and develop novel approaches to address the complexities of different Australian coastal settings
MOD7	Assess the suitability (including evaluation and benchmarking) of existing numerical, probabilistic, and statistical models to predict coastal processes and change in different Australian coastal settings

(Continued)

TABLE 1 | Continued

Coastal Hazards and Climate Change

HAZ1	Quantify potential future change to regional and local wave climates (including storminess) due to global climate variability and climate change
HAZ2	Quantify the impacts of sea level rise on nearshore and estuarine hydrodynamics, groundwater, sediment dynamics, and shoreline change
HAZ3	Quantify the impacts of coastal hazards and climate change on coastal infrastructure
HAZ4	Quantify and reduce uncertainty in forecasts of climate change and sea level rise within the Australian region and their subsequent coastal effects
HAZ5	Quantify the impacts of climate change on coastal marine habitats and their ecosystems (e.g., coral reefs, temperate rocky reefs, and kelp forests) and the potential subsequent implications for coastal dynamics
HAZ6	Quantify the impacts of wave climate variability over different timescales on nearshore and estuarine hydrodynamics, groundwater, sediment dynamics, and shoreline change
HAZ7	Develop frameworks, scenarios, and models for the application and triggering of planned/managed retreat
HAZ8	Quantify the socio-economic impacts of climate change on coastal communities
HAZ9	Quantify the socio-economic and legal impacts of planned/managed retreat
HAZ10	Quantify the impacts of climate change on coastal sand barrier ecosystems (e.g., coastal dunes, wetlands, and mangroves) and the potential subsequent implications for coastal dynamics
HAZ11	Identify opportunities and methods for ecosystem adaption, preservation, and restoration to promote naturally resilient coastal systems
HAZ12	Evaluate the effectiveness of different adaptation strategies in different Australian coastal physical and socio-economic settings
HAZ13	Establish a nationally consistent methodology for the development of coastal hazard assessment guidelines and coastal planning and management strategies that are fit for local-scale application
HAZ14	Develop hazard, impact, and risk assessment techniques to better mitigate coastal zone climate change impacts on the adjacent built environment
HAZ15	Develop decision support systems, tools, and guidelines to facilitate effective coastal management in different Australian coastal settings (including for ICOLLs)
HAZ16	Innovate climate change adaptation and response funding models and policy frameworks through a collaborative process involving all stakeholders
HAZ17	Quantify the impact of climate change on bioclastic sediment production by tropical and temperate carbonate organisms and the potential subsequent implications for coastal sediment budgets

Engineering Solutions

ENG1	Identify and quantify potential sand sources for beach nourishment that are proximal to locations of high coastal risk and investigate the potential impacts of sand extraction on sediment budgets
ENG2	Quantify the impact of coastal structures on sediment dynamics and coastal morphology at different spatial and temporal scales
ENG3	Develop novel and enhanced designs for adaptive resilient coastal infrastructure and coastal protection structures (including working with nature and softer options)
ENG4	Quantify the effectiveness of adaptive resilient coastal infrastructure and nature-based solutions and develop guidelines for their application in different Australian coastal settings
ENG5	Assess the effectiveness, cost, and feasibility of existing and future coastal protection strategies and design standards (including tolerance to extreme events)
ENG6	Develop best-practice approaches for the selection, design, implementation, and optimisation of beach nourishment schemes that seek to maximise efficient sediment use including collaboration between adjacent land managers
ENG7	Develop strategies to evaluate and minimise environmental impacts associated with infrastructure development and dredging in coastal environments
ENG8	Develop economic and policy frameworks that improve the viability of beach nourishment as a long-term adaptation strategy, including the use of offshore sand reserves where it is deemed necessary
ENG9	Increase opportunities and access to physical modelling for use in the development and assessment of structural design
ENG10	Develop new technologies and evidence-based best-practice criteria to mitigate environmental impacts of the processes associated with beach nourishment (including, but not limited to, offshore and estuarine sand extraction, sediment placement, and disposal or reuse of undesirable sediment fractions, e.g., fines)
ENG11	Develop guidelines to adapt traditional coastal infrastructure (both existing and new projects) for innovative eco-integrated designs (e.g., incorporating habitats for marine life)
ENG12	Assess industry standards for the performance, suitability, and cost effectiveness of new and existing materials for coastal structural design
ENG13	Evaluate the social acceptability of current and future coastal protection options
ENG14	Develop standards for the design and application of multipurpose artificial reefs in different Australian coastal settings

Communication and Collaboration

COM1	Grow public understanding of coastal dynamics and the impacts of hazards and climate change on coastal environments and communities by developing communication tools and citizen science opportunities
COM2	Identify barriers that hinder collaboration and coordination between coastal research (physical, ecological, and social), consultancy (engineering, economics, and legal), and government (policy, management, and planning) stakeholder groups
COM3	Develop effective tools and training to assist coastal managers in engaging and educating their communities to enable more informed participation in coastal management and planning
COM4	Identify barriers that hinder collaboration and coordination between levels of government and across government departments and agencies (i.e., vertical and horizontal collaboration)

(Continued)

TABLE 1 | Continued

COM5	Develop innovative and best-practice approaches for designing risk analysis to enable effective communication to communities and decision makers
Infrastructure, Innovation, and Funding	
IIF1	Acquire additional funding to support coastal research, collaboration, and education
IIF2	Design and construct platforms dedicated to nearshore and coastal observation and monitoring
IIF3	Develop novel instrumentation to obtain measurements (e.g., processes and morphology) that are currently unachievable
IIF4	Increase capability and support for national IT infrastructure (processing and storage)
IIF5	Increase marine research vessel capacity (for both nearshore and deep-water marine research)

Priorities are grouped into the seven categories and appear in order of weighted mean scores, with the priority ranked 1 in each category having the highest weighted mean score. Priority codes are listed in the left-hand column.

graphs. The weighted means were calculated by starting with the simple mean score ($\bar{R}$, as calculated above), which was then multiplied by the percentage of all responses with scores ≥ 3 ($\frac{n_{\geq 3}}{N}$; i.e., including "N/A" and "Unsure" responses). This value was then multiplied by the percentage of all responses with scores of 5 ($\frac{n_5}{N}$) such that:

$$\bar{R}_w = \bar{R} \frac{n_{\geq 3}}{N} \frac{n_5}{N}$$

The weighted mean scores thus represent the degree to which priorities had a high proportion of above-average support (scores ≥ 3) and a high proportion of very strong support (scores = 5) across the respondents. Priorities that received a relatively high proportion of both ≥ 3 and 5 scores typically sit above the envelope of deviation around the mean weighted score for priorities in each category. Those that sit around the mean received average proportions of ≥ 3 and 5 scores, and those that fall below the envelope received relatively lower proportions of ≥ 3 and 5 scores. While the weighted mean scores provide useful insights on the perceived relative impact and/or urgency

of each of the 74 priorities by the collective CGE community, we emphasise that all priorities reflect multiple individual nominations and are therefore considered to be important and supported by the CGE community.

RESULTS

A total of 74 priorities (**Table 1**) were identified across seven categories during Stages 1 and 2 of this horizon scanning and collaborative priority setting exercise. All 74 refined priorities distil similar nominations and, therefore, each represents an important focus for the CGE community. This was reflected in the priority scoring results where the average proportion of ≥ 3 scores (indicating above average support) across all priorities was 84% and the lowest was 63%. Furthermore, the highest combined proportion of "Unsure" and "N/A" responses (indicating that the respondents did not support the priority or weren't sure if it was important) was only 12%.

The priority scoring (Stage 3) reveals important insights about the CGE research and stakeholder community's perspectives on the relative impact and urgency between priority categories and between individual priorities. There was a statistically significant difference between categories as determined by a one-way ANOVA test on the scoring from all survey participants ($F(6, 9383) = 12.61$, $p << 0.001$). A diffogram (**Figure 4**) compares the (unweighted) mean scores between each of the priority categories against the means of all other categories. Pairs of categories (identified as the intersections between horizontal and vertical grey lines) that had significantly different mean scores as identified by a multiple pairwise comparison of group means using Tukey's HSD criterion ($\alpha = 0.05$) are denoted by blue circles and diagonal lines that do not intersect the 1:1 line. Pairs of categories that do not have significantly different mean scores from each other (their diagonal line intersects with the 1:1 line) are denoted by the red circles and diagonal lines. For example, the *Data Collection and Collation* category had the highest average score (3.92; indicated by its vertical and horizontal positions on the figure) while the *Engineering Solutions* category had the lowest average score (3.62). These two means are significantly different as shown by the diagonal line representing this pair which does not intersect the 1:1 line. This result perhaps reflects that the *Data* and *Engineering* categories represent two ends of CGE research and application.
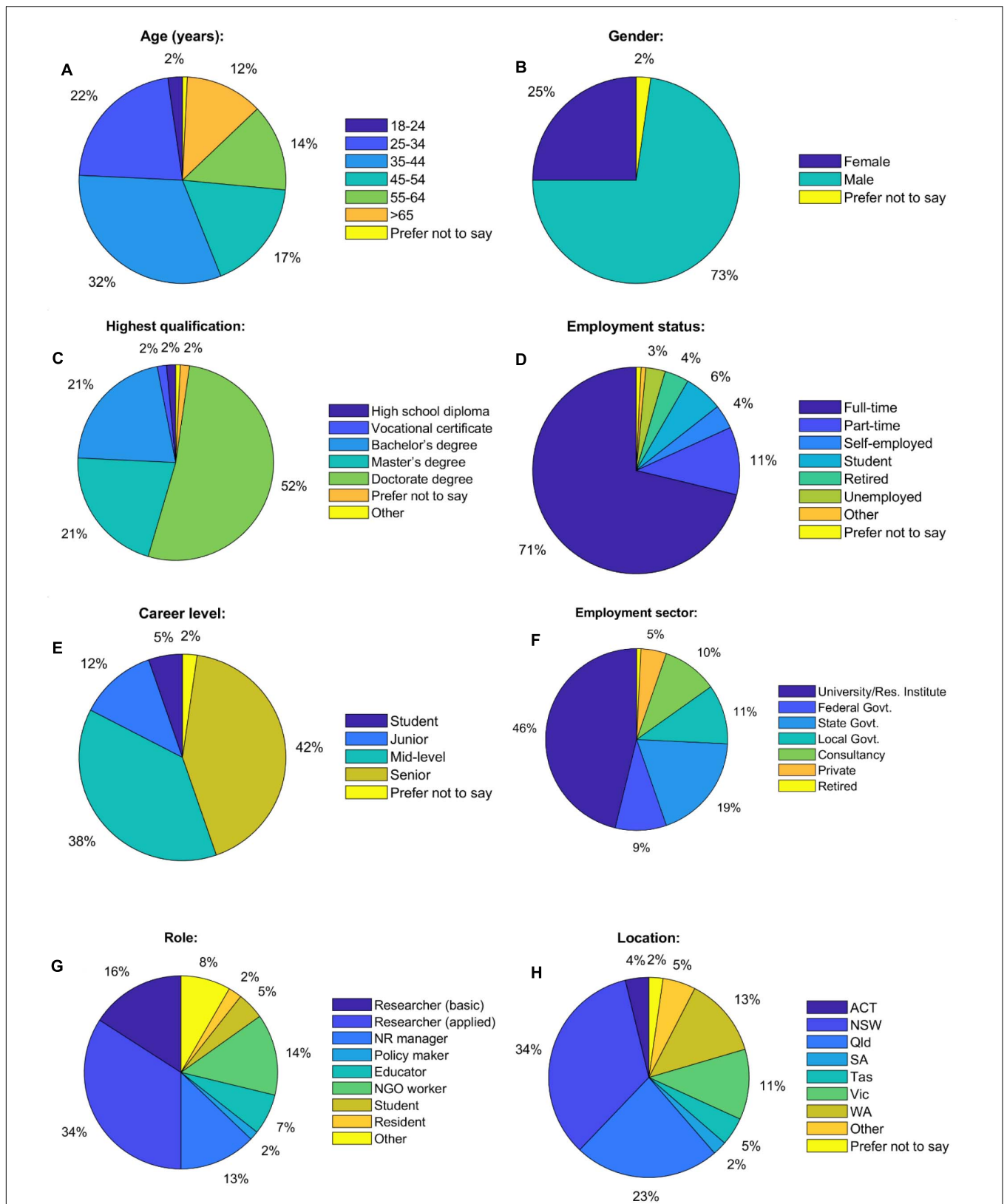
FIGURE 3 | Summary of demographics of participants in the survey in Stage 3 of the research prioritisation process. Percentages are shown for all demographic groups of 2% or greater. Panels **(A–H)** represent the responses to the demographic questions 2–9 in Supplementary Material 1.1 respectively.
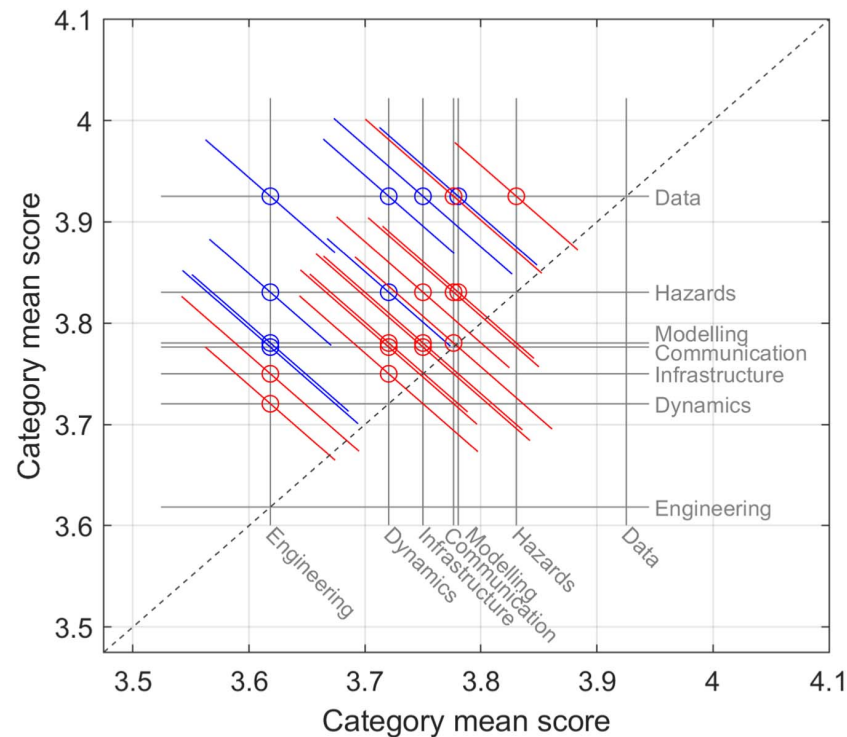
FIGURE 4 | Diffogram showing multiple comparisons of the mean scores of the categories based on the results of the one-way ANOVA test. Horizontal and vertical grey reference lines display the means of each category. Open circles represent comparisons of all 21 pairs of means and straight lines represent 95% confidence intervals. Blue circles and lines represent pairs of means that are significantly different from each other at the $p = 0.05$ level. Red circles and lines indicate pairs of means that are not significantly different from each other, i.e., those with confidence intervals that intersect the diagonal reference line.

Data collection, collation, management, and access underpins the full scope of CGE research and thus influences priorities across all categories, whereas engineering solutions represent the application of completed CGE research.
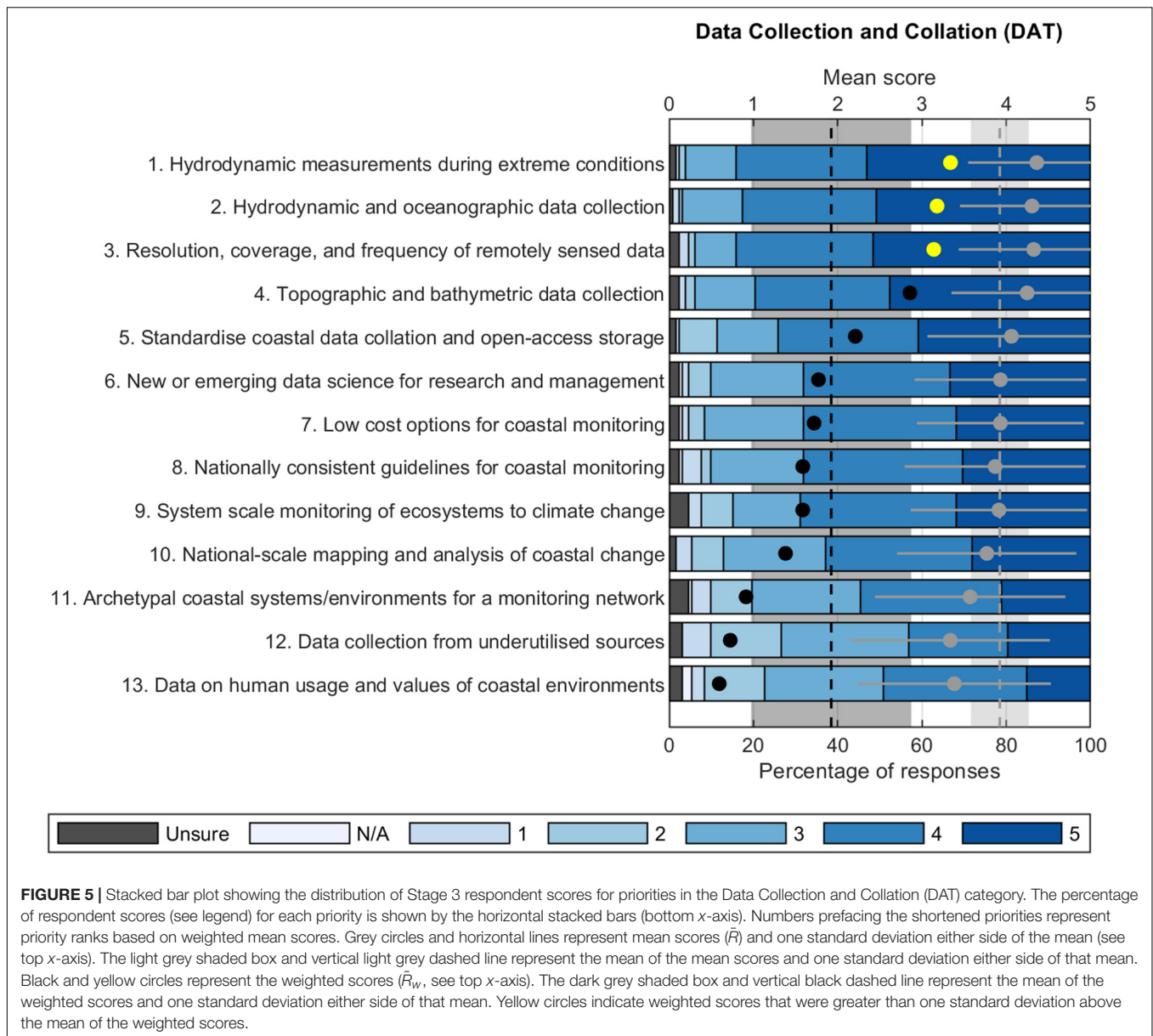
In the following subsections we describe the priorities identified by the CGE community in each category. In each figure we identify the priorities that received unified and strong support from the CGE community based on the weighted mean scores (highlighted in yellow). We consider a vast majority of respondent scores ≥ 3 to represent unified support from the Australian CGE community and consider a high proportion of top (5) scores to reflect strong, unified support. Typically, these above-average scoring priorities have impact across the range of CGE subdisciplines. The short priority titles used in **Figures 5–11** can be compared with the full titles shown in **Table 1** using the alphanumeric code for each priority.

Data Collection and Collation

The CGE community identified 13 priorities related to the collection and collation of data (**Figure 5** and **Table 1**). These priorities identify a need to increase the coverage, frequency, and resolution of hydrodynamic and morphodynamic data collection, improve the accessibility of cost-effective monitoring programs, standardise data collection, undertake system to national-scale monitoring programs that provide consistent and comparable

conceptual model outcomes, collect data from under-utilised resources (e.g., citizen science, indigenous knowledge, and human usage data), and establish open-access data storage infrastructure. The support for data collection and collation was very strong, having the highest average score (**Figure 4**) and for 11 of the 13 priorities, $\geq 80\%$ of respondents scored ≥ 3.
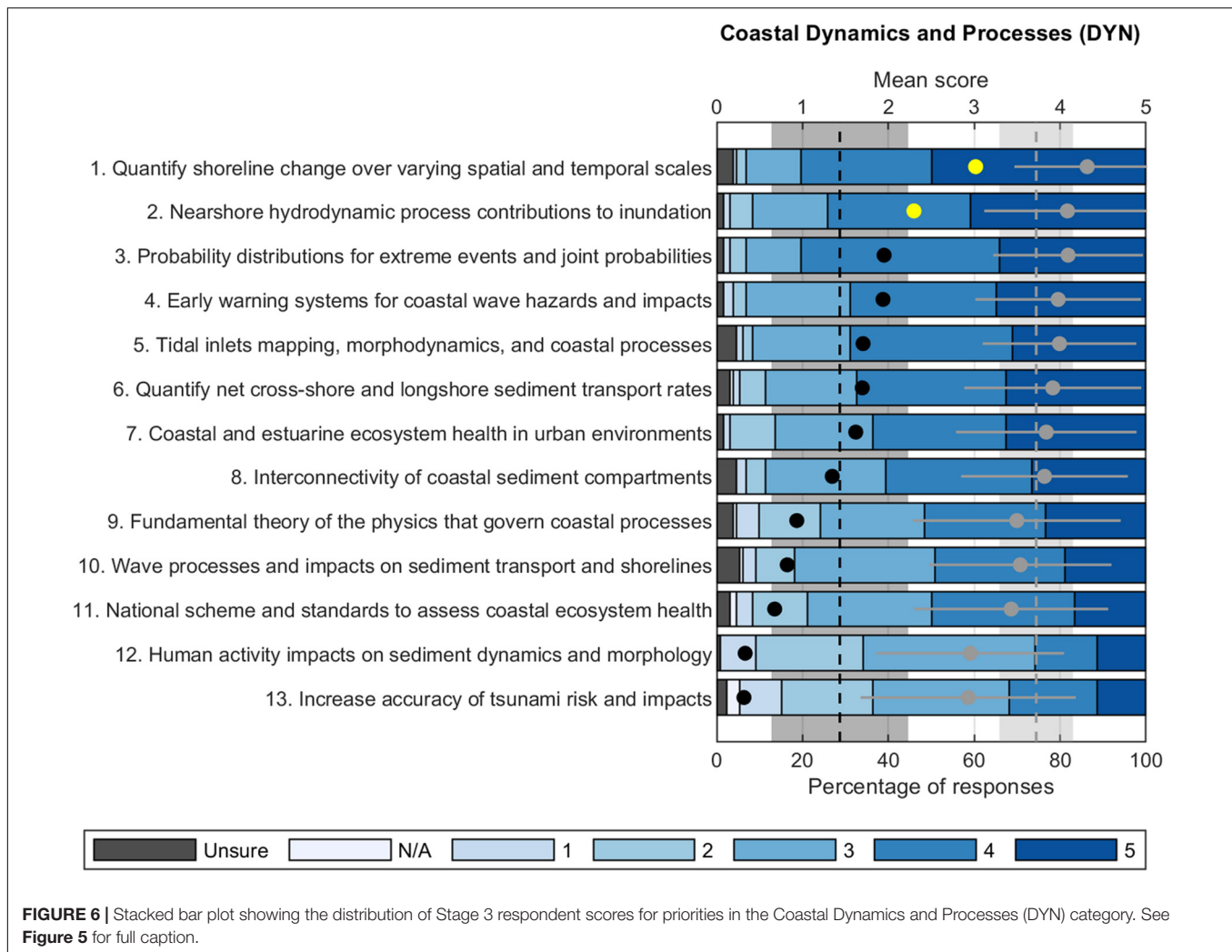
The need to collect a wide array of data using a range of techniques (DAT1-4) was strongly supported by the community and each were rated as 'critical' (scores of 5) by $\geq 50\%$ of respondents. There was general agreement that there was a need to standardise data collected for storage, indexing, and sharing through open-source platforms (DAT5), explore new and emerging data science methods for research and management (DAT6), as well as lower-cost options for coastal monitoring (DAT7). There is also a need to develop national coastal monitoring guidelines (DAT8) and undertake system and national scale monitoring of ecosystems (DAT9) and coastal change (DAT10). While the need to collect data from underutilised sources (DAT12) and on human usage and values of coastal environments (DAT13) were identified by the CGE community, those priorities received fairly distributed scoring. The scoring suggests that whilst the need for these data is recognised, many in the CGE community may consider this to be the domain of other disciplines or may not be equipped with the skills to obtain or use these data.

FIGURE 5 | Stacked bar plot showing the distribution of Stage 3 respondent scores for priorities in the Data Collection and Collation (DAT) category. The percentage of respondent scores (see legend) for each priority is shown by the horizontal stacked bars (bottom x-axis). Numbers prefacing the shortened priorities represent priority ranks based on weighted mean scores. Grey circles and horizontal lines represent mean scores ($\bar{R}$) and one standard deviation either side of the mean (see top x-axis). The light grey shaded box and vertical light grey dashed line represent the mean of the mean scores and one standard deviation either side of that mean. Black and yellow circles represent the weighted scores ($\bar{R}_w$, see top x-axis). The dark grey shaded box and vertical black dashed line represent the mean of the weighted scores and one standard deviation either side of that mean. Yellow circles indicate weighted scores that were greater than one standard deviation above the mean of the weighted scores.

Coastal Dynamics and Processes

Thirteen priorities related to coastal dynamics and processes were identified by the CGE community (**Figure 6** and **Table 1**). The majority (11 of 13) of these priorities broadly cover sediment- and morpho-dynamics as well as coastal inundation on both open and sheltered coasts including in tidal inlets. The need to develop early warning systems for coastal hazards, erosion, and inundation was also identified, as well as the need to assess (including developing of a national scheme, standards, and baseline) and maximise the health of a range of coastal ecosystems. These four overarching issues are closely related to the focus of most of the CGE community and are also critical for effective coastal management.

The two most highly ranked priorities were the need to quantify shoreline change over varying spatial and temporal scales (DYN1) and nearshore hydrodynamic process contributions to inundation (DYN2). These priorities were ranked by 75–80% respondents as being of 'critical' importance. Although we also note that the need to understand the probability and joint probability distributions for extreme events also scored very highly (DYN3). The high ranking of these priorities is consistent with the need for such knowledge to develop early warning systems for coastal wave hazards and impacts (DYN4). There was also broad support for a wide range of priorities associated with coastal and tidal processes as well as ecosystem health (DYN5-11). Two priorities scored ≤ 3 in 70–75% of

FIGURE 6 | Stacked bar plot showing the distribution of Stage 3 respondent scores for priorities in the Coastal Dynamics and Processes (DYN) category. See **Figure 5** for full caption.
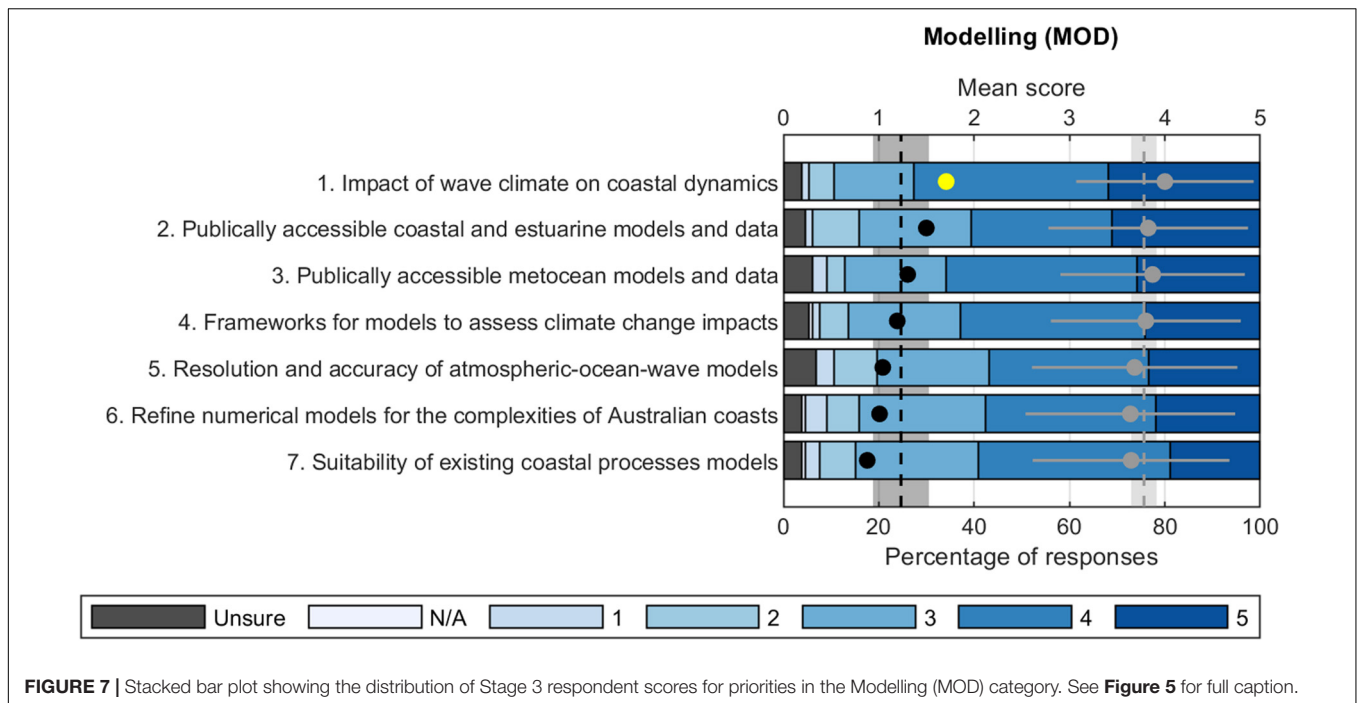
the responses: quantifying the impacts of human activities, transportation (e.g., vehicle use on beaches), and recreation (e.g., boat wakes) on overall sediment dynamics and coastal morphology (DYN12), and quantifying with greater accuracy the risk of tsunamis and their impacts (DYN13). Both of these priorities are highly specific in nature and less likely to have broad reaching impacts across the CGE community.

Modelling

The CGE community identified seven priorities related to numerical modelling (**Figure 7** and **Table 1**). These priorities include enhancements to numerical models to connect future wave climates to coastal dynamics, increased resolution, accuracy, and accessibility of numerical models developed for Australia (including their data streams), as well as assessments of the suitability of existing models for application to the Australian coast. The need for a framework and associated guidance for the application of numerical, probabilistic, and statistical models to assess climate change impacts in different Australian coastal settings was also identified. These priorities suggest that there is a need to establish a consistent approach to connect climate

change forcing scenarios to the impacts that these will have on coastal environments and communities.

The need to quantify the impact of future wave climate scenarios on coastal sediment transport and shoreline dynamics (MOD1) received the strongest support (>70% scored this priority ≥ 4). This was supported by priorities that would contribute to that outcome such as developing national and regional scale numerical hindcast and forecast models (ideally with publicly accessible data streams) for coastal and estuarine hydrodynamics and morphological change (MOD2) and metocean processes (MOD3). In addition to these numerical models, a need for a framework and guidance on the application of a range of models (e.g., numerical, probabilistic, and statistical) to assess climate change impacts in different Australian coastal settings was also identified (MOD4). This suggests that the community seeks consistent guidance on the tools and approaches that should be applied for that work to be considered "best practice" in different coastal settings, and access to the necessary tools and data to achieve those goals. Three well supported (i.e., > 80% scored ≥ 3) but more focussed priorities were identified, which highlighted the need to increase the

FIGURE 7 | Stacked bar plot showing the distribution of Stage 3 respondent scores for priorities in the Modelling (MOD) category. See **Figure 5** for full caption.

spatial and temporal resolution of established coupled metocean models (MOD5), develop coastal and estuarine models tailored to capture the complexities of the Australian coastline (MOD6), and assess and benchmark the suitability of existing numerical, probabilistic, and statistical models to predict coastal processes and change in different Australian coastal settings (MOD7).
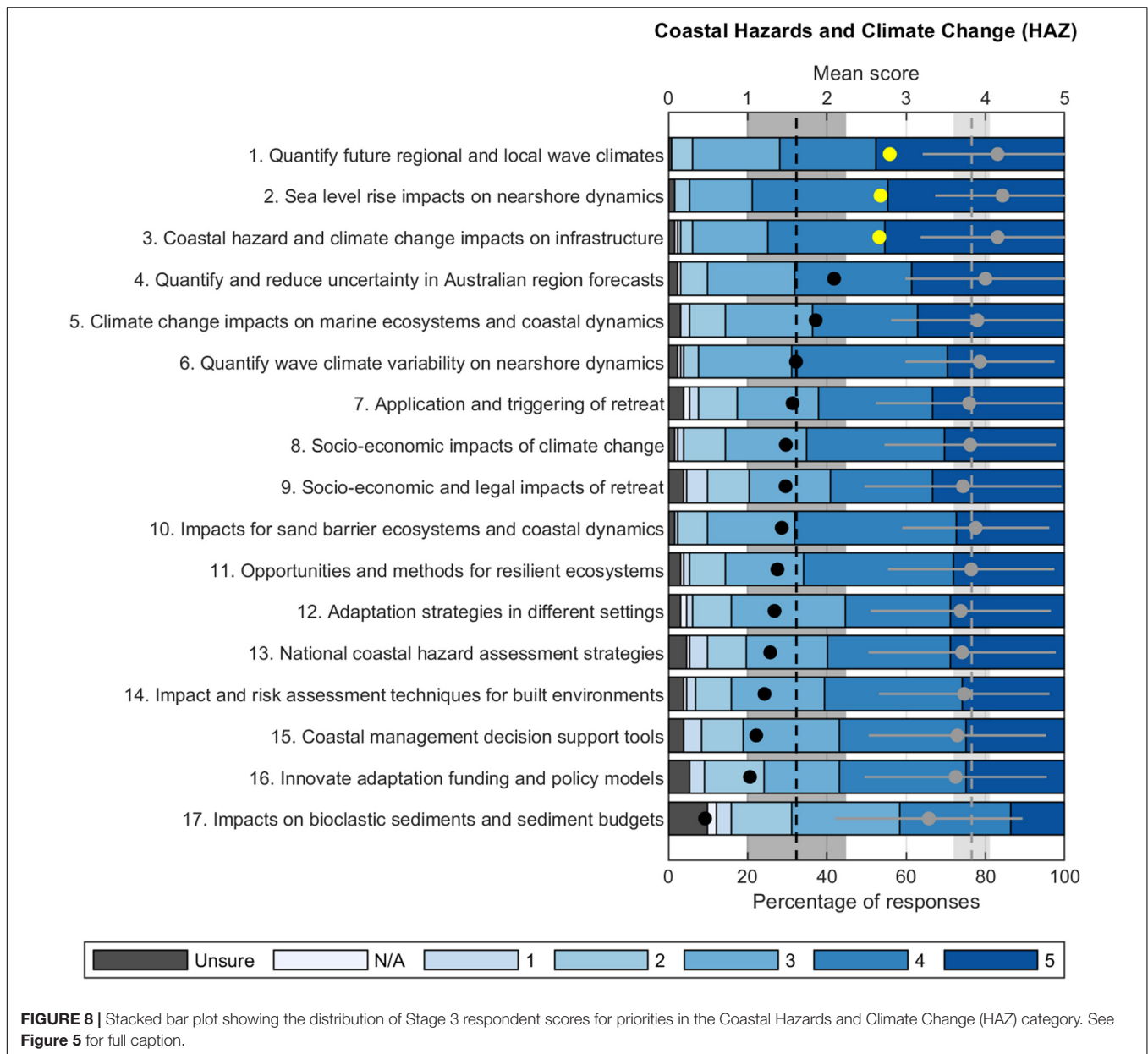
Coastal Hazards and Climate Change

Seventeen priorities related to coastal hazards and climate change were nominated by the CGE community (**Figure 8** and **Table 1**). The priorities include quantifying the physical and biological impacts of coastal hazards and climate change effects in coastal environments, developing and enabling hazard mitigation and climate adaptation options, and understanding and predicting the socio-economic implications of both impacts and potential solutions. They summarise key challenges for CGE research in contributing toward resolving socio-economic and environmental issues arising from the establishment of communities in dynamic coastal environments, their effect on fragile ecosystems, and the increasingly realised hazards and impact of climate change.

Three priorities stand out as receiving near-unanimous and strong support from the CGE community. They include the influences and impacts of climate change on: coastal wave climates (HAZ1), hydrodynamics and sediment transport (HAZ2), and coastal infrastructure (HAZ3). This demonstrates a clear need to improve the community's understanding of the potential for local-scale coastal change from global- to regional-scale drivers of coastal hazards such as storm climatology and sea-level rise. Three other priorities (HAZ4, HAZ6, and HAZ10) that are closely related to the first three above also received unified support (with > 90% of respondents scoring ≥ 3) but a lower

(< 40%) portion of top scores. Most other priorities in this category scored strongly receiving > 80% scores ≥ 3 and 25–30% top scores. They cover techniques to address current and future impacts of coastal hazard and climate change, particularly to enable coastal adaptation across the range of Australian physical and ecological coastal settings and coastal communities, and will have impacts on a range of other coastal management disciplines (e.g., economics, legal, policy, planning, stakeholder consultation). Notably, addressing some of these priorities will require expertise beyond the dominant physical/natural science and engineering focus of the CGE research community, which highlights the need for cross-disciplinary collaborative research (e.g., HAZ8, HAZ9, and HAZ 16). One priority (HAZ17) scored below average and focussed on only one component of coastal sediment budgets. Despite the abundance and significance of bioclastic sand in many Australian beach systems, the very focussed nature of HAZ17 likely contributed to low scoring.
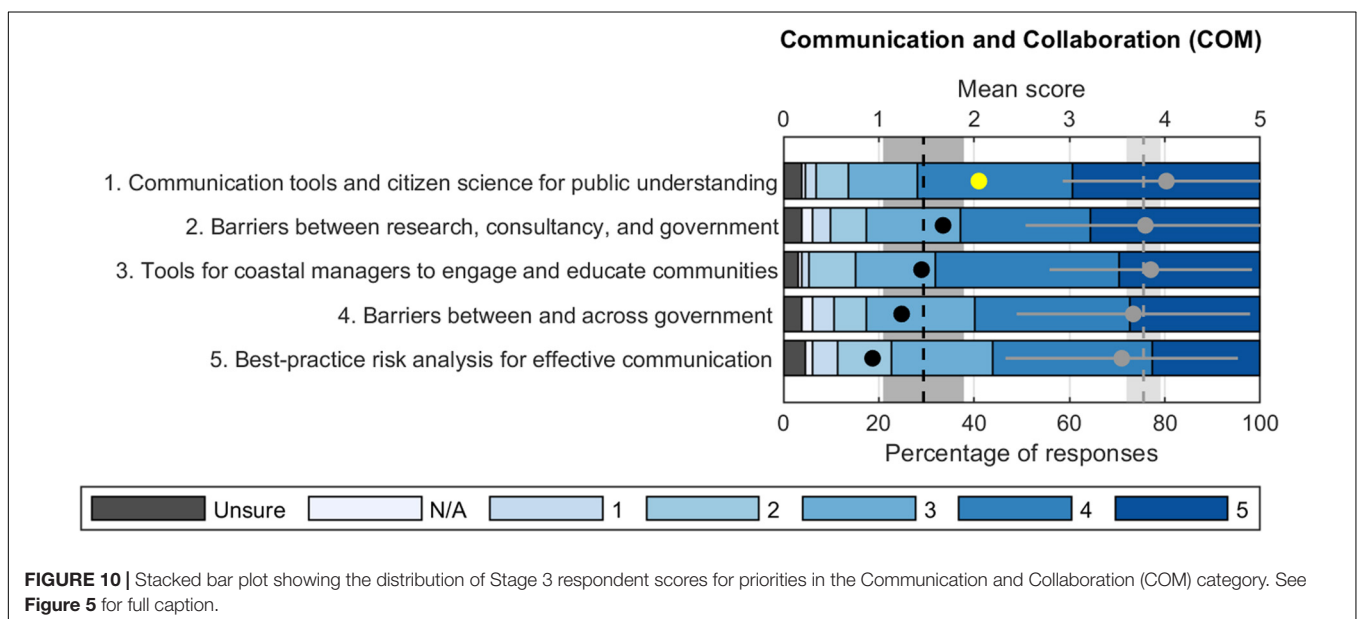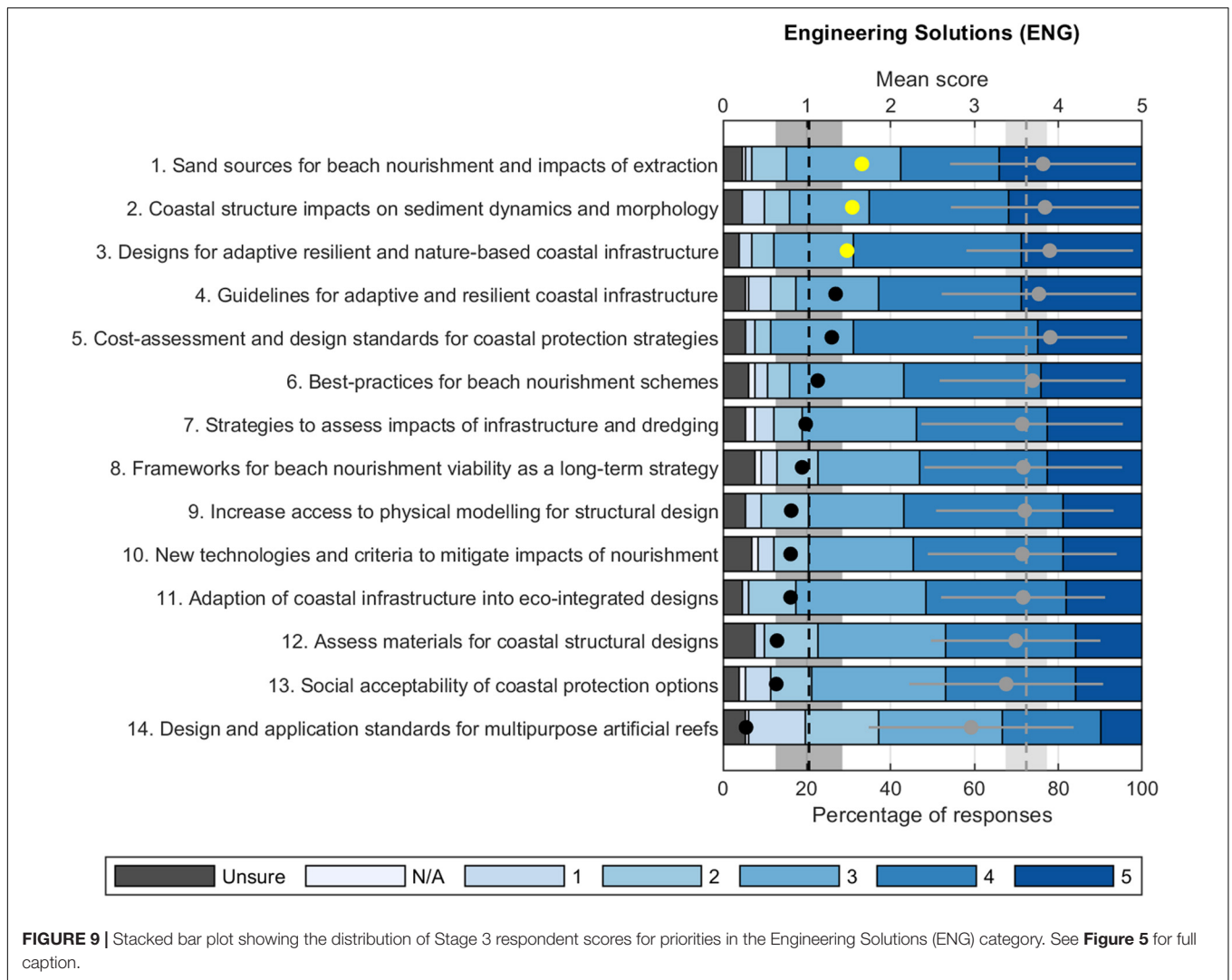
Engineering Solutions

There were 14 diverse priorities related to coastal engineering solutions that were identified in this study (**Figure 9** and **Table 1**). In general, these priorities encapsulated many of the contemporary 'end user' challenges facing the coastal geoscience and engineering community. For example, the need to identify and quantify potential sand sources for beach nourishment that are proximal to locations of high coastal risk and investigate the potential impacts of sand extraction on sediment budgets (ENG1), quantifying the impact of coastal structures on sediment dynamics and coastal morphology at different spatial and temporal scales (ENG2), and developing novel and enhanced designs as well as guidelines for adaptive resilient coastal infrastructure and coastal protection structures

FIGURE 8 | Stacked bar plot showing the distribution of Stage 3 respondent scores for priorities in the Coastal Hazards and Climate Change (HAZ) category. See **Figure 5** for full caption.
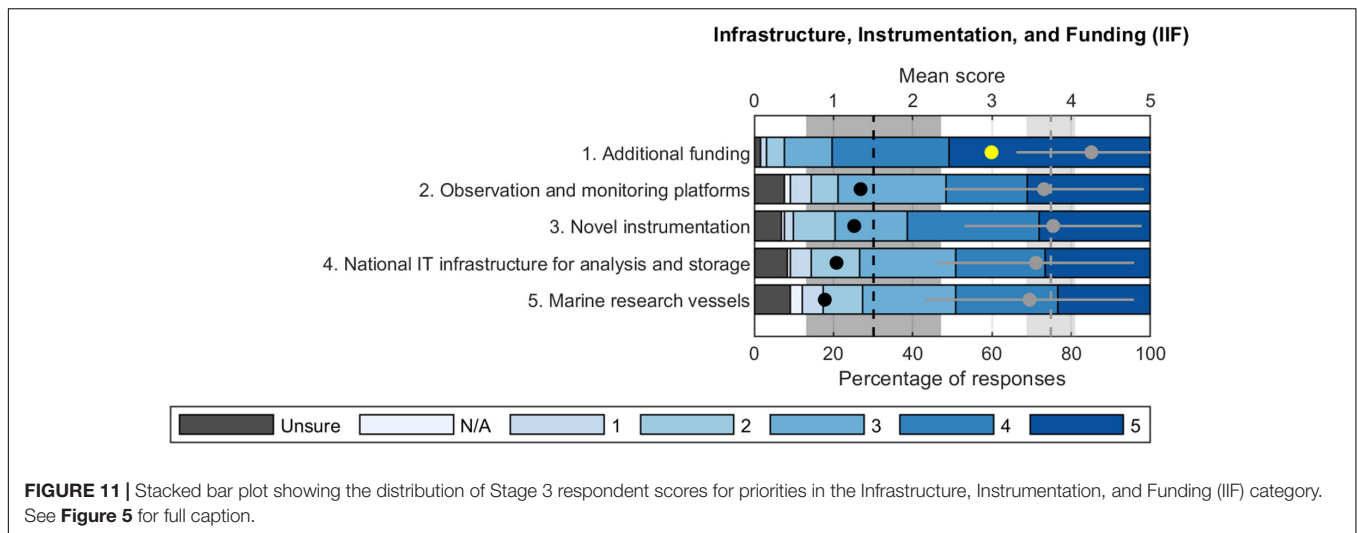
including working with nature and softer options (ENG3 and ENG4). The focus of this category on end solutions to coastal hazard impacts is likely to explain the lower scoring of priorities in this category (weighted mean ≈1) relative to other categories as summarised in the diffogram (**Figure 4**).

There were four issues that encapsulated many of the priorities in this category: (1) the need to identify sources of sediment for nourishment, as well as define best practice, frameworks, and innovative ways to extract and use this sediment (ENG1,6-8,10); (2) development and specification of novel, eco-integrated, resilient, and adaptive infrastructure (ENG4,11); (3) quantification of the cost and feasibility of "nature based" solutions along with the development of strategies and design standards for their implementation (ENG3); and, (4) the need to quantify the impacts of coastal structures on sediment dynamics

and coastal morphology at different spatial and temporal scales (ENG2). The remaining priorities were more specific and identified the need for cost-assessments and design standards for various coastal protection strategies (ENG5,14), the social acceptability of various coastal protection options (ENG13), and the suitability of materials used in coastal structures (ENG12). The three lowest ranking priorities (ENG12-14) were notable in their focus on particular types or aspects of engineering solutions. The social acceptability of coastal protection options (ENG13) is perhaps not a core consideration of the CGE research community and may be outside the scope of physical coastal research or considered the domain of other disciplines. The scalability of artificial reefs (ENG14) as generic management options and suitability to Australian coastal settings means that potential applications are limited relative to other options.

FIGURE 9 | Stacked bar plot showing the distribution of Stage 3 respondent scores for priorities in the Engineering Solutions (ENG) category. See **Figure 5** for full caption.

FIGURE 10 | Stacked bar plot showing the distribution of Stage 3 respondent scores for priorities in the Communication and Collaboration (COM) category. See **Figure 5** for full caption.

FIGURE 11 | Stacked bar plot showing the distribution of Stage 3 respondent scores for priorities in the Infrastructure, Instrumentation, and Funding (IIF) category. See **Figure 5** for full caption.

Communication and Collaboration

The CGE community identified five priorities related to communication and collaboration (**Figure 10** and **Table 1**). The priorities relate to growing community understanding of coastal dynamics, hazards, and climate change through improved engagement and participation, identifying and addressing barriers to collaboration, and effective communication across the CGE stakeholder community. The development of best-practice approaches for designing and applying risk analysis to support decision making by communities and coastal managers was identified as an aspect of communication in particular need of improved techniques.

Scoring in this category was characterised by a steady decrease in scores from above average weighted means (≥2) to the lowest scoring priorities (with weighted means of ∼1). One priority (COM1) attracted unified and strong support as reflected by ∼70% of respondents assigning a scoring of 4 or greater. This priority is about growing community understanding of coastal dynamics, hazards, and climate change through improved communication tools and participation in citizen science initiatives. Closely related to this priority was the need for tools to assist coastal managers to engage and educate communities (COM3), which attracted broad overall support. The CGE community recognised that barriers between research, consultancy, and government were a particular issue (COM2) but also that barriers between and across governments and their agencies were also present (COM4). Finally, the CGE community identified a need to develop best-practice risk analysis for effective communication (COM5). This indicates that there is a need to not only develop clear and consistent methods for risk analysis, but also to develop new strategies to communicate risk concepts to government and community stakeholders.

Infrastructure, Instrumentation, and Funding

Five priority areas associated with infrastructure, instrumentation, and funding were identified by the CGE community (**Figure 11** and **Table 1**). The priorities include raising additional funding to support coastal research, collaboration, and education (IIF1), the creation of platforms and instruments that would increase the coastal observation and monitoring capability (IIF2-3), the establishment or enhancement of national IT infrastructure to support data management, modelling and analysis (IIF4), and increased marine research vessel capacity to access underwater coastal environments (IIF5).

The need for additional funding to support CGE research, collaboration and education was almost unanimously supported and received a top score from more than half of Stage 3 respondents, highlighting this priority as foundational to the community. This reflects the reality that additional resources, effort, and infrastructure are required to address many of the priorities identified by the CGE research and stakeholder community in this study. However, we note that careful consideration of how best to allocate additional resources to achieve the greatest impact is required. For example, the development of fixed and mobile platforms for coastal monitoring and experimentation would directly contribute to many of the priorities identified in the *Data Collection and Collation* category and the *Coastal Dynamics and Processes* category. The other priorities in this category scored similarly, with platforms and novel instrumentation for measuring coastal processes and dynamics marginally preferred over additional IT infrastructure and research vessel capacity.

DISCUSSION

Priorities of the Australian Coastal Geoscience and Engineering Community

Through this study, the Australian CGE community has identified 74 activities across seven categories that are seen as clear priorities to increase the impact of CGE research and application in addressing key issues for coastal societies. The

community has ranked these priorities through a scoring process that has identified the priorities that the community sees as being most critical. There was strong support across the community for nearly all priorities identified, with 91% of priorities receiving scores ≥ 3 (i.e., above average levels of support) from $\geq 75\%$ of respondents. This indicates broad consensus amongst the community on most priorities that were identified. This is a notable outcome, as similar exercises have previously concluded in comparatively broad priorities (or objectives; e.g., Wisz et al., 2020) with a mixed or undefined level of support from the respective community (e.g., Jarvis and Young, 2019). Our methods may thus serve as a template for identifying priority activities for research communities in other discipline areas.

The results presented here are unique as we use an established sampling methodology (Sutherland et al., 2011) supplemented with novel score analysis methods and apply it to a previously unstudied area with a specific discipline focus and present the views of the discipline community. Further, the priorities were structured such that they are achievable at the project level, i.e., by a small number of researchers or stakeholders in 3–5 years. This differs from other studies aiming to identify priority research questions in that they often cover a very broad field (e.g., ocean/marine/coastal research as a whole; Rees et al., 2013; Rudd, 2014; Jarvis and Young, 2019), assess priorities at a global scale (e.g., Rudd and Lawton, 2013; Rudd, 2014, 2017), pose very wide-ranging questions (e.g., Wisz et al., 2020), provide relative rankings of priorities rather than absolute rankings (e.g., Rudd and Lawton, 2013; Rudd, 2014; Greenslade et al., 2020), or present a list of priorities without rankings or scores (e.g., Jarvis and Young, 2019; Wisz et al., 2020). While these alternative approaches have their advantages (e.g., Best Worst Scaling can be advantageous when trying to compare a large number of research questions), they do not identify specific, actionable projects that could be achieved within individual jurisdictions nor rankings for these priorities that also reflect perceived urgency, a gap that this study sought to fill. Comparing across the categories, *Data Collection and Collation* stands out as receiving the highest scores with all priorities receiving scores of ≥ 3 from at least 73% of respondents and a category average score (3.92) that was significantly higher than four of the other six categories (**Figure 4**). *Hazards and Climate Change* was the second ranked category, with a category average score (3.83) that was significantly higher than two of the other six categories. In contrast, *Engineering Solutions* was the lowest scoring category (category average score of 3.62; **Figure 4**), with 81% of respondents assigning an above average score (≥ 3) and only 23% a top score (**Figure 9**). Although comparison at the category level provides broad insights on areas of need (**Figure 4**), the categories were only intended to group similarly themed priorities and vary in the number and diversity of priorities. To reveal more about the preferences of the Australian CGE community, stand-out priorities were identified from each category using the weighted means (**Figures 5–11**).

When all 74 priorities are compared together, 11 stand out as receiving the strongest support (i.e., with weighted mean scores greater than one standard deviation above the mean of all the weighted scores; see priorities highlighted by red outlines in **Supplementary Figure 4**). These 11 priorities identified a critical need for: additional coastal data collection including topographic and bathymetric, hydrodynamic, oceanographic, and remotely sensed data (DAT2-4) as well as improved data compilation and access (DAT5); improved understanding of extreme events and the quantification of future impacts of climate change on nearshore dynamics and infrastructure (DAT1, HAZ1-3); enhanced quantification of two key coastal dynamics and process issues, namely shoreline change and coastal inundation (DYN1-2); and, additional funding to support CGE research and application (IIF1). Addressing many of these priorities would enhance the community's understanding of a broad range of current and future coastal change processes or hazards (i.e., they are foundational priorities) and we therefore consider them to be critical for informing coastal management and sustaining coastal communities. This study shows that a balance of fundamental data collection, critical knowledge advancement, and enabling forces (through additional resources or barrier removal) are required. This reflects the outcomes of similar priority setting exercises proximal to the disciplines considered in this study (e.g., Greenslade et al., 2020).

In reviewing the nature and scoring of the priorities within (see Section "RESULTS"; **Figures 5–11**) and between categories (**Supplementary Figure 4**), it became apparent that many of the highest scoring priorities had a potential breadth of impact across the growth and application of knowledge and/or through the development of tools and solutions to address CGE problems such that they may be described as *foundational*. For example, priorities concerned with increased data collection (DAT1-3), distinguishing process and response in shoreline change (DYN1), understanding the influence of climate change on coastal hazards (HAZ1-3), and the availability of research funding (IIF1) all scored very highly. Addressing these priorities would not only directly impact the progress of researchers and stakeholders across much of the CGE community, but it would also indirectly enable or progress efforts to develop knowledge or solutions that are the focus of other priorities identified by the community. In contrast, below-average scoring priorities were usually more *focussed* in their potential impact across CGE research and application. For example, priorities concerned with collecting data on human usage, values, and interventions in coastal environments (DAT13, DYN12), assessing risks from tsunami hazards (DYN13), the impacts of climate change on bioclastic sediment production (HAZ17), and developing standards for multipurpose artificial reefs (ENG14), all scored lower than average in their respective categories. Addressing each of those priorities would have impact in a particular area of application or for specific end-users. It is critical to highlight that focussed priorities should not be dismissed as insignificant as they may well represent crucial steps in developing knowledge or applications for specific settings. Rather, they often have ambition that lies closer to a particular solution or application than is the case for foundational priorities. Focussed application priorities may also more closely reflect the values and needs of individual communities. Average scoring priorities most often had *broad* potential impact across

the CGE community, such that they might not enable or contribute to addressing as many other priorities as those with foundational impact, but they had greater potential flow on impacts than focussed priorities. Categorising each of the 74 priorities as having *foundational*, *broad*, or *focussed* impact is not without a degree of subjectivity. Instead, we offer this characterisation as an exploratory framework that may assist others in interpreting their own priority scoring results and as useful nomenclature for describing the potential impact of addressing individual priorities.

While all 74 priorities represent an important focus for the CGE community, many of these priorities are not independent activities. Rather, they have multiple co-dependencies with a clear cascade of knowledge. Here, we have synthesised the priorities and identified the major linkages as well as critical research enabling activities to obtain a holistic perspective of how CGE research and implementation will drive strong outcomes for society (**Figure 12**). It is clear that almost all of the CGE priorities are underpinned by funding whether it be for baseline data collection (e.g., Dhu et al., 2017; Gavin et al., 2018; Greenslade et al., 2018; Amirebrahimi et al., 2019) or for research projects that target a particular research priority. Funding is also critical to ensure CGE teaching continues in tertiary institutions to ensure continuity of suitably qualified and knowledgeable CGE researchers, practitioners, and stakeholders within the community. Given that much of CGE research has an outcomes-driven focus, experimental and field data underpins the vast majority of priorities that were identified. Such data will drive enhanced understanding of coastal hydro-, sediment-, and morpho-dynamics, strategies to maximise coastal ecosystem health, and quantification of coastal hazards. Yet it is evident from this study that the CGE community identifies an absence of sufficient data and that further data collection is of critical importance. Furthermore, there is also a need for novel and specific infrastructure and instrumentation to support this data collection. The acquisition of data and an improved understanding of many important processes critical for coastal geoscience and engineering, will drive improvements to numerical models, engineering designs, and coastal management strategies. It will also refine forecasts of climate change impacts on nearshore dynamics and ecosystems. Notably, almost all priorities would benefit from the removal of barriers to collaboration and coordination.

Analysis of respondent demographics found that the priorities described in this study can be considered representative of the Australian CGE community (**Box 1**). There was a high level of engagement and interest in the results of the survey, with 73% of Survey 1 participants and 81% of Survey 2 participants leaving their contact details to be informed of the study results. Due to the snowball sampling methods used, survey invitations sent to mailing lists, and the anonymous nature of the survey responses, a rate of response to the survey based on individual invitations cannot be calculated. However, a minimum response rate can be obtained by cross-referencing details of participants who left contact details to be kept informed of the results of the project with the contact list of individuals who were invited to participate in the survey. This revealed *minimum* response rates of 35% and 27% for Surveys 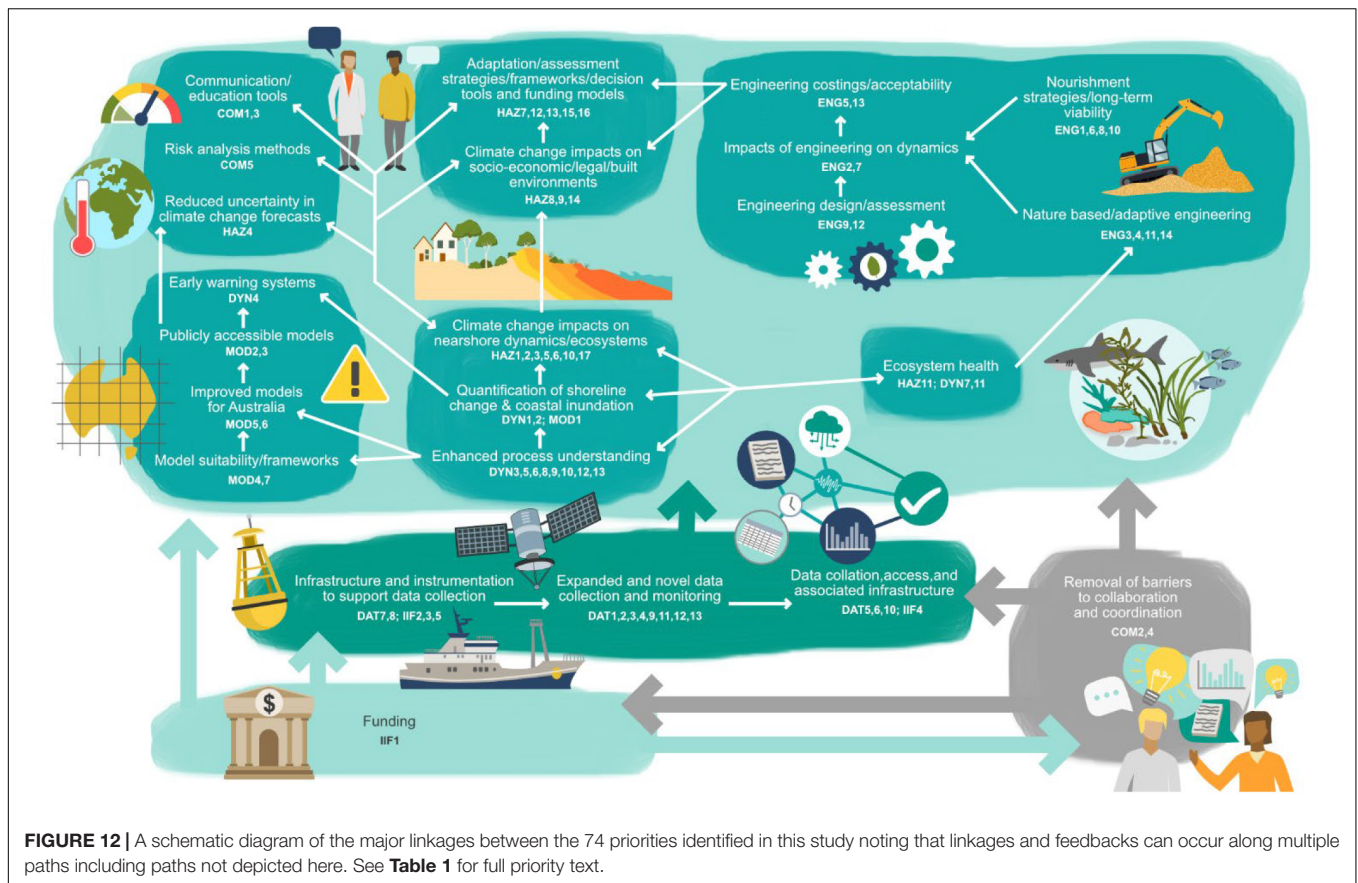1 and 2, respectively, which demonstrates an engaged and interested Australian CGE community. Previous horizon scanning and priority setting surveys in marine and coastal science have experienced response rates in the range 15–35% (Rudd and Lawton, 2013; Rudd, 2014).

Emerging Themes and Opportunities

The 74 priorities identified in the Results and discussed in the previous subsection were derived from the responses received in Survey 1. In Survey 2, there was an opportunity for participants to nominate any additional activities that they thought should be listed as priorities that were notably absent from the 74 priorities presented. This allowed respondents to identify holes in the priorities list that might not have been apparent when working from a blank canvas. Themes that connect the additional priorities identified are discussed below, noting that each theme emerges from multiple related responses. These themes represent opportunities to further develop the impact of CGE research in addressing key issues for coastal societies.

Participant diversity amongst CGE researchers and stakeholders has traditionally lacked broader gender and cultural representation. Gender inequality in geoscience has been recently documented in Australia (Vila-Concejo et al., 2018; Handley et al., 2020) and globally (Bernard and Cooperdock, 2018; Tooth and Viles, 2020) confirming that CGE remains a male-dominated discipline. The demographics presented in this study highlight similar biases toward under-representation of non-male identifying members of the community. This finding emphasises the ongoing need to remove barriers to participation and enable progression for non-male identifying researchers and stakeholders. Contemporary CGE research and practice largely emerged in response to catastrophic impacts from natural hazards (e.g., 1953 North Sea floods) and challenges encountered in European wars during the 20th century (e.g., beach landings). As such, knowledge growth and solution development has often overlooked longer term perspectives and site-specific knowledge held by indigenous and first nations peoples (e.g., Bayliss et al., 2014; Fischer et al., 2019; Rist et al., 2019), with consequent limited participation and representation in practice. Multiple respondents identified the need to facilitate greater input from traditional knowledge into CGE practice highlighting the need for strategies to foster more diverse inclusion. Although some recent studies have considered cultural diversity in, for example, geoscience more broadly (e.g., Bernard and Cooperdock, 2018), we are not aware of any analyses of cultural diversity within CGE research in Australia. We did not seek details of our respondent's cultural backgrounds, however, future priority setting exercises might do so to measure representation. Additionally, over 75% of respondents were over the age of 35 indicating an under-representation of youth in the CGE community surveyed. Whilst age does not necessarily reflect career level, a greater focus on the relative importance of different priorities between generations would be insightful, however, the structure of our study did not enable these trends to be clearly identified. Finally, an additional priority that was identified in the second survey was the need for increased mentoring and fostering of young members of the CGE community.

Communication, collaboration, and education is often a top-down approach where the CGE research community strives to

FIGURE 12 | A schematic diagram of the major linkages between the 74 priorities identified in this study noting that linkages and feedbacks can occur along multiple paths including paths not depicted here. See **Table 1** for full priority text.

educate the wider CGE stakeholder community and general public. This may be a result of established relationships and norms that have developed between research, industry, and government, as well as the broader CGE stakeholders including the general community and not-for-profit organisations. Studies into community engagement in the areas of natural hazards, climate change, and environmental management have shown a historical bias of engagement models involving technical observation and process understanding with communication of results by industry, government, or academics to the community (e.g., Adams et al., 2014; Baudoin et al., 2016; Lawrence et al., 2018; Hemmerling et al., 2019). A need for more bottom-up approaches to collaboration and communication was identified in the Stage 3 survey open response results. Such an approach may result in a shift to more localised objectives centred around the needs of individual communities, increased engagement by the local community, and increased consideration of local community sentiment. Citizen Science initiatives, which were strongly supported by the Australian CGE community (**Figure 10**), provide a useful means to initiate bottom-up strategies (Dean et al., 2018). Key societal issues under the focus of CGE research are primarily experienced at the community level where impacts manifest, appropriate solutions are required, and compromises between strategies, policies, and community expectations play out (Adams et al., 2014). Zagonari (2008) found that differences in values between developed and developing nations influenced whether or not coastal management strategies

were perceived as successful, with developing nations particularly benefiting from community-based (bottom-up) approaches to engagement in coastal management, while top-down approaches to coastal management and engagement produced more successful outcomes in developed countries where the local or general population is less engaged and attaches indirect values to coastal quality. Despite these findings, Zagonari (2008) recommends that bottom-up approaches should be adopted in developed nations in scenarios where local stakeholders are engaged and communities' value of coastal quality is high.

Learning from history in the context of the application of CGE research to address past problems was another theme that emerged in the open responses to the Stage 3 survey, with several responses suggested using learnings from the history of coastal management in Australia to inform future policy development and decision-making. Notable comments included: *review the current state policies, their implementation by local governments and practicality for coastal management, policy and decision making*; *understanding the socio-political acceptability of previous strategies and policies*; and, *identify gaps in the current state of coastal geosciences research, monitoring and management*. Whilst the priorities identified here highlight the need for nationally consistent approaches for coastal monitoring, research, and management, it is important to also recognise that coastal setting and community values and expectations are inherently variable at the local scale (e.g., Zagonari, 2008; Graham et al., 2018), and that may influence the success or otherwise of solutions

implemented in practice. Where there is a lack of consistency in jurisdictional and legal management of the coastline (e.g., Thom et al., 2018; Thom, 2020), implementing nationally devised approaches might be problematic, and therefore, such approaches must be appropriately flexible so as to address the needs of local managers and communities.

Multidisciplinary approaches such as those espoused by the Integrated Coastal Zone Management paradigm (Sorensen, 1993), were also highlighted in the open responses to the Stage 3 survey. Applying *geological knowledge* and more rigorous consideration of *ecosystem, biodiversity, and habitat* processes and values in CGE research and practice were cited in multiple responses. On the former, the need to increase connections across the CGE research community spanning geology to processes can deliver more comprehensive and holistic perspectives to CGE practitioners, while new frameworks can enable the application of geological knowledge to address coastal management and planning challenges (e.g., Thom et al., 2018; Pearson et al., 2020). On the latter, the progressive recognition and inclusion of habitats and ecosystem functions into conceptual and numerical coastal dynamics models can allow for the investigation of coastal processes and responses in natural settings (e.g., Moore et al., 2018), which extends to testing system responses to the implementation of nature-based solutions. Understanding the role of ecological processes in coastal geomorphic evolution thus elevates the significance of ecosystem processes beyond intrinsic ecological values (e.g., Renschler et al., 2007). Increased multidisciplinary research bringing together physical and biological disciplines in coastal research could develop the missing knowledge and tools to achieve the goals of integrated coastal zone management in practice.

In reviewing the 74 priorities identified through our survey methods and the additional emerging themes and opportunities described above, we wonder how our results might inform the direction of CGE in other jurisdictions. Australia, as a nation, generally has the capacity to address these priorities, and the potential benefits to society that would derive from modest increases in available resources and a focus of activities in particular areas (e.g., those with perceived foundational impact) are readily attainable. Furthermore, the immediate threat of coastal hazard impacts to coastal communities is moderate when compared with other settings globally, although the medium- to long- term risks are extreme. Previous horizon scanning exercises in developed countries have identified that the lack of designated resources and funding can hinder the solution of achievable (i.e., not overly ambitious) research priorities (e.g., Rudd, 2014), such as the 74 priorities identified here. This highlights the value of these exercises in coordinating research direction and effort. The resources, capabilities, and risk settings that characterise Australia will vary in other jurisdictions, along with other factors such as community expectations, values, and cultural diversity and we expect that these factors would influence outcomes if this study were repeated elsewhere. It is also important to note that horizon scanning exercises that primarily engage researcher and professional stakeholders may not fully reflect the values and priorities of the broader community (Graham et al., 2018).

MAXIMISING THE IMPACT OF COASTAL GEOSCIENCE AND ENGINEERING RESEARCH

The outcomes of this priority setting exercise can be applied to guide policy development and decision-making in Australia and beyond. Furthermore, this study shows the research that, if carried out, will contribute to addressing key practical challenges but also national level strategies and plans. For example, addressing the priorities identified here would feed into the seven grand challenges identified in the National Marine Science Plan (National Marine Science Committee, 2015) with many priorities aligning with the leverage points (identified as the needs common to the grand challenges) and with the gaps in marine science capabilities and investment. All of the CGE priorities identified here would ultimately contribute to three of the key practical research challenges identified under the "Environmental Change" theme in the Australian National Research Priorities (Department of Industry, Innovation and Science, 2015), which are to conduct research that will lead to: improved accuracy and precision in predicting and measuring the impact of environmental changes caused by climate and local factors; resilient urban, rural, and regional infrastructure; and, options for responding and adapting to the impacts of environmental change on biological systems, urban and rural communities, and industry. Further, many of the priority research areas identified here would address the "Coastal Inundation Protection Strategy" which was deemed a "High Priority Initiative" by Infrastructure Australia in their latest Infrastructure Priority List (Infrastructure Australia, 2020).

It is important to note that although this exercise has developed a list of priorities for CGE research and application in Australia, the priorities represent the views of the CGE community at a single instance in time. While the priorities detailed here are unlikely to become outdated in the short- to medium-term, the evolving state of CGE research and technology, and the manifestation of coastal hazard impacts in a changing climate, may alter the CGE community's views on which priorities are most critical and urgent. Other factors that might influence evolving priorities could include shifts in government policy. Hence, it would be ideal to revisit this exercise on a regular basis (e.g., every 5 years) to reassess the CGE community's views and scoring of individual priorities to identify any changes in those seen as most critical and to discover novel emerging priorities. The priorities identified here also have the potential to inform the development of a national coastal research program for Australia, similar to the established United States Coastal Research Program[2] or the European Union Horizon2020 projects, such as COASTAL Collaborative Land-Sea Integration Platform[3] or EuroSea[4].

Our exercise in priority setting has highlighted the critical role of CGE research. While the scientific and engineering contributions are generally well recognised, this study shows that

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[2]https://uscoastalresearch.org/
[3]https://h2020-coastal.eu/
[4]https://eurosea.eu/

CGE research also contributes to the identification and enabling of social, environmental, and economic benefits. These benefits are attained through the proactive management of coastal hazard impacts as well as informed planning to mitigate the potential impacts of growing coastal risk, particularly in a changing climate. Rather than waiting for impacts to transpire from natural hazard risks, resulting in unnecessary social, environmental, and economic burdens, CGE research can guide advanced planning and preparedness at timescales from days to decades. The societal value of CGE research can be measured in: engaged, informed, and resilient communities with site-specific, tailored, and agile plans to adapt to a changing environment; the preservation of coastal habitats and species and their critical ecosystem services and hazard cushioning, in spite of growing pressures from climate change and human development; and, avoided costs that would be otherwise borne from fragmented and reactionary responses to a dynamic and changing environment. None of the above is possible without the evidence and insights gathered by CGE researchers with the ambitions identified in this study.

Paramount to success is the availability and accessibility of the funding and resources necessary to achieve the goals the community have identified and, crucially, the removal of barriers limiting engagement and collaboration with the broader CGE stakeholder community. At a time when the funding and resources available to CGE research and teaching are actively diminishing in Australia and other jurisdictions globally, the advantages of investment in and support for CGE research that is proportionate to the growing benefits for contemporary and future societies could not be greater nor clearer. In a resource-limited setting, the findings in this study provide guidance in the form of a collective disciplinary perspective to support a more strategic approach to funding CGE research. Although this analysis has been carried out in Australia, global collaboration in modern research and the prevalence and commonalities of the challenges faced by coastal communities due to increasing pressures from coastal hazards in a changing climate means that the findings presented here are likely applicable to other settings. We encourage the pursuit of open priority setting exercises in other jurisdictions to capture the influences of regional differences in coastal setting, community expectations, and challenges faced on perceived priorities for CGE research and application.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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ETHICS STATEMENT

AUTHOR CONTRIBUTIONS

HEP led this study with all authors contributing to all aspects of the work including project design, survey delivery, data analysis and interpretation, and manuscript writing.

FUNDING

ACKNOWLEDGMENTS

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.645797/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the
absence of any commercial or financial relationships that could be construed as a
potential conflict of interest.