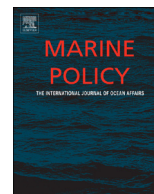




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The pace and progress of adaptation: Marine climate change preparedness in Australia's coastal communities



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ABSTRACT

This study provides an assessment of local government progress in adaptation to marine climate change in Australia's coastal communities. Globally, coastal communities are vulnerable to a diversity of marine climate change impacts, and adaptation responses will need to be tailored to suit each unique socio-ecological situation. The responsibility of adaptation planning is largely placed on municipal councils, yet much of this activity goes unreported in the peer-reviewed literature. Through a meta-analysis of municipal planning documents this study reveals that in general, progress is in the early stages. Many councils have no plans, and the presence of plans seems to be related to the magnitude of council income as well as participation in regional or international adaptation networks. Of those councils that do have plans, only half have progressed beyond the 'understanding the problem' phase. Additionally, the focus of marine adaptation planning is generally restricted to one driver – sea level rise. Changing sea surface temperatures and ocean acidification were largely ignored, despite predicted impacts on coastal ecosystems and the communities that interact and depend on them. While it is often assumed that developed countries have the capacity to adapt to climate change, this study indicates that for some important aspects of marine change in Australia, this capacity is not always translated into action by local councils. The development and refinement of progress indicators such as those used in this study will be increasingly important as tools for establishing baselines and tracking adaptation into the future.

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1. Introduction

Evidence is growing that climate change is already impacting the bio-physical characteristics of the oceans; including sea surface temperature change, sea level rise, and acidification [7]. In consequence, coastal communities are vulnerable to a range of climate change impacts, from changes to sea-levels and coastlines, changes in climate, and changes in the marine ecosystems they depend on. Australia is faced with the full gamut of climate change impacts and, stretching from tropical to temperate climates, provides a useful case study for the challenge of coastal adaptation globally. Of all the elements of marine climate change faced by Australia's coastal communities, by far the most widely acknowledged and discussed is inundation and loss of habitable land from sea level rise [1,18]. This is often experienced through acutely damaging flood events caused by a combination of increasing high tide levels and storm

activity [20]. Changes in the marine environment are increasingly impacting marine ecosystems, flowing on to impact marine socio-ecological systems [37] and the coastal communities that form part of these coupled systems [45]. Socio-ecological systems are impacted in complex ways; both through threats to infrastructure, and through threats to livelihoods and industries.

1.1. The nature of threats to socio-ecological systems

Threats to infrastructure are fairly straightforward. In Australia, more than \$226 billion in commercial, industrial, road and rail, and residential assets are potentially exposed to inundation and erosion from climate change. As a result, the ability to provide critical infrastructure and essential community services such as electricity generation, emergency services and waste management is likely to be severely impacted [15,16].

Threats to livelihoods and industries are more complex. Because changes in marine conditions are tightly linked to changes in marine ecosystems, they are predicted to have far ranging impacts on industries such as aquaculture, fishing and tourism that depend on marine resources, and on the coastal communities that rely on these industries. For instance, changes in marine conditions will increase vulnerability in the aquaculture industry, both generally

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through increases in incidence and impact of diseases, and site specifically by reducing the suitability of certain areas because of inundation, unpredictable fluctuations in salinity and temperature, and increased risk of damaging storm events [17]. Furthermore, changes in primary and secondary productivity and species range shifts will alter the availability and abundance of wild caught marine species, where and how they are accessed and who is able access them [14]. Historically, fluctuations in fish stocks have had major economic impacts on societies, with communities dependent on a limited range of species or a limited area being most vulnerable. The exact nature of changes in fisheries due to climate change is difficult to predict given the complexity of the ecosystems within which fisheries are embedded [5]. What is clear is that many fisheries are highly susceptible [29] and this brings increased uncertainty to the Australian fishing industry [15] and the many coastal communities that rely on this sector. Coastal tourism is also likely to be affected, with roughly a third of Australia's tourism industry centered around regions highly vulnerable to climate change [26], most notably the Great Barrier Reef [46]. Nature tourism is an important economic activity in many coastal economies, and mostly consists of small operators vulnerable to changing tourist preferences that hinge on perceptions of 'pristine nature' [15]. Finally, coastal communities are likely to face a pervasive loss of business and employment due to the relocation of firms and industries away from the coast as climate change related disruptions become more common. The diverse and well publicised risks associated with climate change, whether perceived or actual, could seriously damage the economies of many coastal communities [31].

1.2. The local manifestation of marine climate impacts

The way that climate change in the marine environment manifests in coastal communities will be dependent on local conditions and systems. Australia's coastline spans the tropics, the subtropics and the temperate zone, presenting a vast array of coastal ecosystems and oceanographic features. Global climate change has, and will continue to manifest locally in radically different ways due to this variety of climates and location-specific circumstance, such as the ocean warming hotspot in the southern state of Tasmania [40].

While the localised impacts from changing coastlines are reasonably tangible, impacts from changing marine ecosystems are often complicated by the response of interacting social systems. These will be particular to the nature of interaction a community has with these marine systems and how that interaction is likely to change. For instance, climate driven marine range shifts [9] may encourage the development of new charter fishing opportunities in north east Tasmania [35]. In contrast, range shifting marine jellyfish species, such as Irukandji, may cause the southward relocation of tourism activities in Queensland [11]. Understanding a coastal community as part of a socio-ecological system [32] is important in recognising the way environmental change impacts human systems and in understanding the consequences of human responses. These reciprocal impacts and feedbacks can obscure the best way to adapt to change [38], and how a community responds can have either a dampening or compounding effect on the way this change manifests in ecological systems [10].

1.3. Implementation of adaptation action

The responsibility for implementing adaptation action has thus far largely fallen to local government. As locally specific responses are needed, municipal governments are widely considered best positioned to understand, interpret and predict the local implications of global climate change. Local governments are often perceived as the most appropriate level of government to implement

adaptation initiatives [22]. The Australian federal government has positioned local councils on the 'frontline' of national adaptation [39] and as the key agencies of community change.

While this seems like a logical arrangement, the management of marine and coastal areas, their natural resources and the human activities (both proximal and distant) that influence resource condition fall under a diverse range of institutional arrangements from multiple levels of government. This situation is complicated further when attempting to manage ecological and social-economic systems whose boundaries do not mirror the spatial division of municipal or state jurisdictions [12].

1.4. Assessing and reporting adaptation action

While the need to track and understand the progress of adaptation is becoming increasingly apparent, much activity goes unreported in the peer-reviewed literature. To understand the nature of the challenge and address deficiencies in a coordinated and logical way, the progress and pace of adaptation must be assessed and reported [3]. How this progress relates to projected climate change impacts and understandings of community resilience can inform policy and direct further research [21]. Previous reporting of adaptation progress has assessed only the peer-reviewed literature, yet much information is contained in the so-called grey literature, with a particular lack of studies from Australia [22]. Strict reliance on peer-reviewed literature by the IPCC means that much of this available knowledge has been necessarily excluded from the Fifth Assessment Report. This will inevitably lead to underestimation of activity in adaptation reporting, and it seems prudent to develop ways to systematically include grey literature in peer-reviewed analyses of adaptation progress.

With debates over climate change action becoming increasingly politicised, it is important to measure how progress in policy and planning relates to expected impacts in a logical and systematic way. This study presents a meta-analysis of official local government documentation and publicly available information to provide a rapid assessment of local government progress in adaptation to marine climate change in Australia. The official adaptation plans of coastal local governments relating to marine climate change along representative stretches of Australia's coastline were systematically examined to evaluate 'adaptation progress' (as defined by [36]). This work provides an indication of adaptation progress at the regional level for five contrasting Australian coastal regions, and so offers a proxy for progress in coastal climate change adaptation. The development and refinement of methodologies such as this will be increasingly important as tools for establishing baselines and tracking adaptation progress and pace into the future.

2. Methods

Stretches of Australian coastline were selected as case study regions. The regions represented a variety of council sizes (with at least one large urban centre) and different demographic and economic characteristics. Moreover, a wide variety of coastal environments and conditions were represented. The selected areas were in Victoria (from Wyndham to Glenelg), New South Wales (from Botany Bay to Bega Valley), southern Western Australia (from Perth to Albany), eastern Tasmania (from Hobart to Dorset), and eastern Queensland (from Brisbane to Townsville). Western Australia, Tasmania and Queensland were also the subject of another climate change related study (See [35]) which aided in the interpretation of results.

A total of 67 councils present along these stretches of coastline were included in the study. For each local council, all official documentation (such as strategic plans, management plans) that mentioned the words 'climate' and/or 'change' were identified

(using a whole domain word search of the official council website). These documents were then searched for specific statements related to coastal marine climate change adaptation. Only official documentation was used as these are a functional part of the adaptation process, whereas other council published sources such as newsletters and web pages describing council activities are not.

The information gathered was used to determine the adaptation phase of each council and the nature of the adaptations being planned. To this end, specific statements made by an individual council related to marine climate change adaptation were assessed according to; (i) the climate change drivers that were addressed, with the following categories; (a) changing sea surface temperatures (b) ocean acidification (c) simple sea level rise (a change in the position of the coastline due to sea level rise) and (d) complex sea level rise (addressing at least one of the associated effects of sea level rise such as salt-water intrusion or increased storm surge height) (ii) what phase of the adaptation process a council was in, with the following categories; (a) the planned improvement of understanding for potential future adaptive action, or (b) planned actual adaptive action (iii) whether these plans related to; (a) economic or (b) infrastructural adaptation.

In addition to the above primary data, a range of council characteristics were recorded in order to investigate factors important in the development of adaptation plans. Information on income from 2011/2012 rates and total expenditure was gathered from individual council budgets. Information on membership of councils to associations facilitating adaptation was gathered from individual council websites or the website representing the regional, state, or international organisations. Information for each local council was also retrieved from the Australian Bureau of Statistics 2011 census database, including population size, percent of the population involved in the agriculture, forestry and fishing industries.

To explore the relationships between the multiple variables that describe council attributes (population, council income from rates and council expenditure) and those that describe the sophistication of plans (drivers addressed and progress of plans), non-metric Multidimensional Scaling (MDS) was used. This particular MDS analysis used a multivariate distance matrix produced from normalised data using the Gower similarity co-efficient [23]. A similarity coefficient measures the likeness between cases (in this instance, councils) across multiple variables, allowing us to display council similarity as a two-dimensional configuration of points. This type of visualization of multidimensional relationships is particularly useful when variables are a mix of both categorical and numerical data. The

goodness-of-fit of this configuration of points is measured as 'stress'. Stress on a two-dimensional configuration of points is minimised when the distances between points is similar to the distances between samples in all dimensions (variables) in the analysis.

The assessment undertaken does not allow us to assess the sophistication of the process each council has gone through in developing their plans. In order to develop a comprehensive adaptation plan, a council must assess all relevant drivers of change, what impacts those drivers will have on their community and what options best address those impacts (Fig. 1). In addition, developing robust criteria for action that takes into account the inherent uncertainty of marine climate change is essential. Consideration of uncertainty ensures that resources are used in a more appropriate and effective way in response to change [24]. A council may release detailed plans without having progressed through these essential steps, and therefore may artificially appear further progressed through the adaptation process. Another aspect that could not be measured as part of this analysis was the quality and appropriateness of the adaptation response, because that would have required an in-depth understanding of each local situation. For instance, after a detailed assessment and the implementation of monitoring systems, it may be appropriate to postpone further planning until a point in the future when certain indicators of change have been

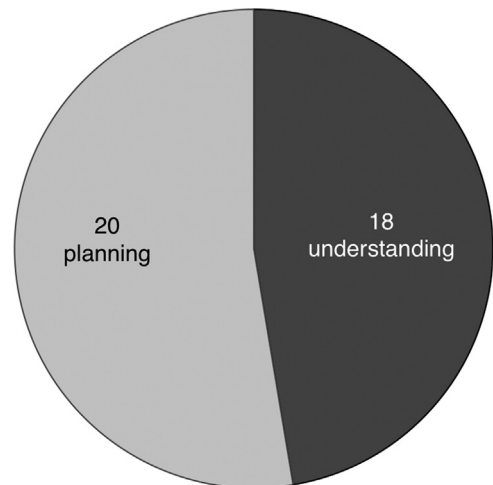


Fig. 2. Count of councils found to be in the planning and understanding phases.

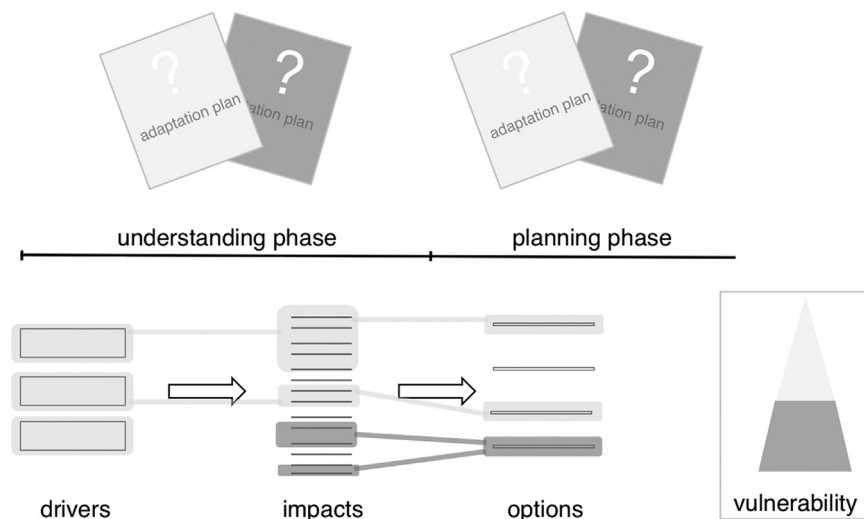


Fig. 1. The adaptation process. The optimal path is shown in light shading, where all drivers are considered and impacts relevant to that council's local situation are addressed; dark shading depicts a council that has selected which impacts to address without prior local assessment. While adaptation plans demonstrate what phase of the process a council is in, they do not explicitly reveal the quality of that process.

reached. Given the purpose of this study was to provide a rapid assessment and give a proxy for the current status of adaptation, it was unable to provide detail or analysis of the process each council had undergone in the development of their adaptation plans. Therefore, the results should not be understood as a judgment of the quality of a council's response.

3. Results

3.1. Adaptation progress

Most coastal communities were in the early stages of the adaptation process. Of the 67 councils in this study, 42% did not have any official marine adaptation plans or the plans were in preparation and not available. While the remaining 58% of councils had released official adaptation plans or had adaptation statements within their general planning documents, they were at very different stages of the adaptation process.

Of the 38 councils that had official adaptation plans, just under half were in the initial phase aimed at 'understanding the problem' (Fig. 2). These councils were still in the process of identifying and understanding marine climate change impacts, and actual adaptation planning had not yet commenced. Their activities included modeling and forecasting, as well as assessments of how these projections relate to existing infrastructure or land use. For example in Fremantle, WA, the Climate Adaptation Plan states that "The City has commenced a detailed modeling exercise of sea level rise" and "will also conduct a risk assessment and begin detailed adaptation planning" (pg 6). Similarly the Sunshine Coast, QLD, council Climate Change and Peak Oil Strategy states that it will "undertake initial vulnerability and hazard mapping to identify major risk areas due to climate change" (pg 51).

A total of twenty councils were in the 'planning phase' [36]. The plans of the councils in this phase detail the ways in which they will incorporate understanding of the impacts of marine climate change, and thus identify the circumstances where adaptation will take place. The plans identify areas that require special consideration, for instance, "development located near a shore line, creek line, river line or waterway is to be undertaken in a manner... which takes into account possible future sea level rise and the associated impacts" (Rockhampton, QLD, Natural Hazards and Climate Change Study, pg 7). The plans also outline when and under what circumstances certain adaptation options will be used, for example, "Shoreline erosion protection measures will only be utilised to protect essential constructed public infrastructure where it is both economic to do so and where there is limited opportunity to relocate the infrastructure at risk" (Fraser Coast, QLD, Shoreline Erosion Protection Structures, pg 3). This indicates that these councils have engaged with the critical step of developing robust

criteria for action. Ten of these councils had detailed plans that addressed specific impacts or identified particular impacted areas. For example Break O'Day council, TAS, had detailed plans to address the increasing inundation of sewage treatment ponds due to sea level rise and increased storm tide heights, events which shut down aquaculture in the bay for one month. In the short term the council plans to "ensure tanks are emptied regularly through education or through a local council funded service" and "waterproof current pumps". In the long term the council plans to "remove tanks" and in either "relocate facility or use alternate form of [sewage] treatment" (climate change strategy, pg 2).

It is clear that some councils within this phase appear further developed than others due to the presence of specific plans as opposed to less specific decision criteria. However, for reasons detailed in Section 3, in some situations councils may have prudently adopted an 'abandon' approach or a 'wait and see' approach, both of which are unlikely to be included as part of official adaptation action plans. Drawing a distinction between groups with detailed decision criteria but no specific plans, and those with specific plans would be premature without a more detailed assessment of their internal decision making process – a task beyond the scope of this study.

3.2. Breadth of focus

Marine adaptation plans often focused on only one driver of climate change. Of the 38 councils with marine adaptation plans all address sea level rise, and 34 restrict their attention to this driver entirely (Fig. 3). The way this driver was dealt with varied. 15 councils

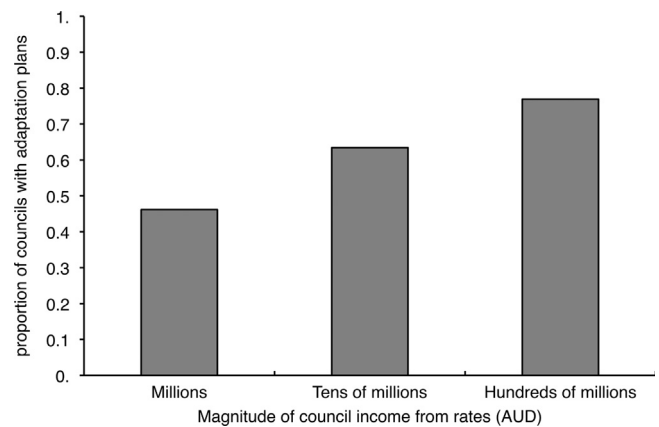


Fig. 4. The proportion of councils with marine climate change adaptation plans grouped according to magnitude of income from municipal rates paid by home owners. Millions (1–9 million) Tens of millions (10–99 million) and Hundreds of millions (100 million and over).

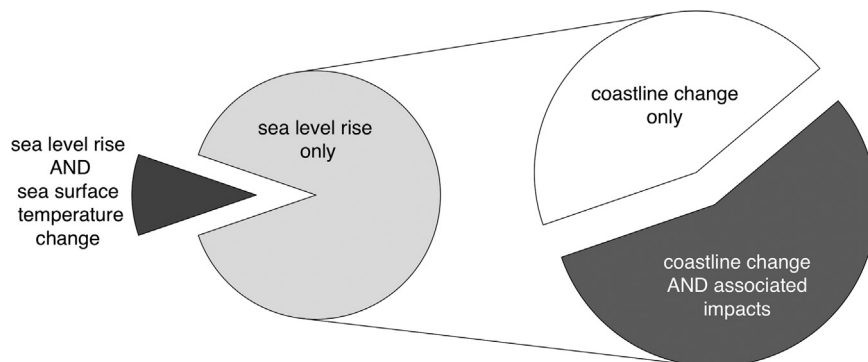


Fig. 3. Break-down of councils according to marine climate change drivers addressed.

simply addressed the issue of an altered coastline, while 23 councils specifically address a breadth of associated impacts such as increases in storm surge frequency and height, coastal erosion, and salt-water intrusion. So while all councils with marine adaptation plans address sea level rise, not all aspects of this driver were covered comprehensively.

In general, the way councils plan for sea level rise is to acknowledge the potential impact and outline how future conditions may be incorporated into current management practices or how current management practices may need to be adjusted. Greater Geelong council (VIC) states that it will “incorporate consideration of climate change in coastal planning decisions through existing planning tools” (Climate Change Adaptation Strategy, pg 25). Eurobodalla shire council (NSW) will achieve this by using “a one hundred year planning period... for all development, operational and strategic decisions that may be impacted by sea level rise” (Interim Sea Level Rise Adaptation Policy, pg 3). The use of current town planning and land zoning practices proved to be a common method of dealing with predicted inundation, for instance Bega Valley, NSW, states that “in urban areas... council may have to look at the delineation of a coastal hazard line or zone and either prohibit/restrict development in these areas” (Natural Resource Planning, pg 6).

While sea level rise is commonly addressed in council marine adaptation plans, the implications of other important marine climate drivers were much less frequently considered. Only four councils included sea surface temperature (SST) increase in their adaptation plans, and none addressed ocean acidification. While for those councils in the planning and implementation stage this may simply reflect the results of prior vulnerability and risk assessments, the absence of the investigation of these drivers among councils in the understanding phase suggests a pervasive lack of focus on these other aspects of marine climate change.

In most cases council documentation discussed impacts of SST changes in terms of the potential impact on marine industries and resource users. For instance, the Sunshine Coast council, QLD, focused on the acute impact of SST increase on the “emergent health risks” from the southward spread of Irukandji stingers (pg 32). The South Perth council, WA, was taking a holistic approach by improving their understanding “of how fishes and their supporting ecosystems respond to changes and how these changes impact biodiversity, recreational and commercial values” (Climate Change Strategy 2010–2015, pg 16). The Tasmanian Break O’Day council’s adaptation plans were more ‘responsive’, aiming to facilitate adaptation in the fisheries and aquaculture industries to changes in the availability and suitability of different fish species under future conditions. They did indicate that potential barriers to change include “government regulations such as species-specific licenses and catch limits” (pg 2). However, no council discussed adaptive management approaches or institutional change as an adaptation measure to marine ecosystem change.

Council adaptation plans were generally focused on council assets as well as town infrastructure (33 and 38 respectively), with little attention paid to the impact of climate change on local economies via its impacts on marine ecosystems, marine resources

or tourism. Only five councils discussed the predicted effect of future marine climate change on local businesses and the potential economic and social flow-on effects. The way in which these five councils planned to adapt was to assist local businesses in treating the symptoms of this change including, for instance, programs that encourage and assist the development of relevant skills (Bayswater, WA, Regional Climate Change Adaptation Action Plan, pg 31) or by ensuring “appropriate planning and policy mechanisms are able to support business” through the “identification of new industries & businesses, urban design & investment in infrastructure” (Belmont, WA, Local Climate Change Adaptation Action Plan, pg 24). In contrast the council of Mandurah goes beyond treating symptoms by developing actions to reduce the problem. The council of Mandurah had focused adaptation measures for the tourism industry, and sought to “incorporate climate change considerations into long-term tourism strategies”, “collect data on coastal recreation demand” and “support research and works for conservation of nature based tourist attractions” (pg 11). Consideration of economic impacts was found only among those councils that considered multiple impacts of climate change beyond sea level rise, and proportionally more common among those that considered more than one driver (i.e. sea level rise and increasing SST) (Table 1).

3.3. Adaptation plans and council attributes

It seems reasonable to hypothesise that the population size, concurrent municipal rates-base and the associated value of funds available to a local council may have an impact on the ability of the council to develop and carry out adaptation plans. Of the councils sampled in this study, the average rates base was roughly \$66 million in 2012, with the smallest council at \$1 million (Nannup in WA) and the largest at \$871 million (Brisbane in QLD). A relationship between higher total income from rates and the presence of marine adaptation plans was observable (Fig. 4). As expected this same relationship applies to population size and total spending, as

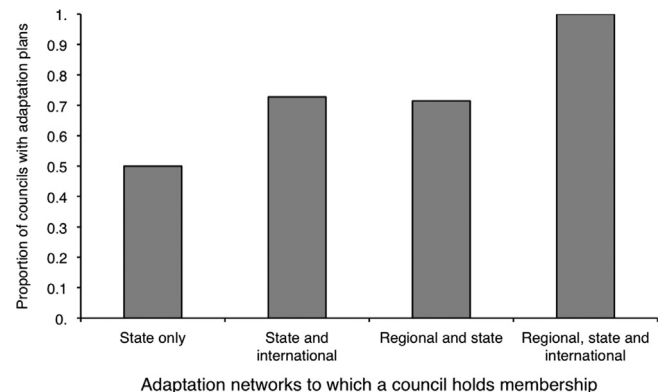


Fig. 5. Proportion of councils with adaptation plans according to their membership to regional, state and international adaptation networks.

Table 1

Count of councils according to drivers addressed and whether their adaptation plans related to the economic impacts of marine climate change or just infrastructural impacts. ‘Associated impacts’ include; coastal erosion, saltwater intrusion and increased storm surge intensity and frequency.

Drivers addressed	Adaptation related to infrastructural impacts	Adaptation related to infrastructural AND economic impacts
Sea level rise	15	0
Sea level rise and associated impacts	15	4
Sea level rise, associated impacts AND sea surface temperature increase	2	2

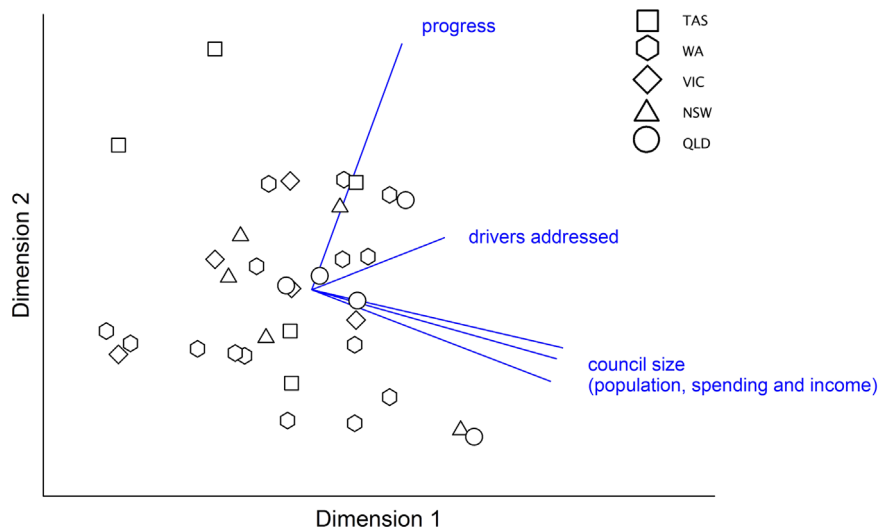


Fig. 6. MDS ordination plot of all councils with marine adaptation plans described by councils attributes (council total spending, council income from rates, population) and sophistication of plans (drivers addressed, progress). Vectors indicate the direction in which council attributes correlate with the ordination space, and points are coded according to state. Stress=0.14.

the correlation of these two variables with income from rates is 0.973 and 0.958 respectively.

The presence of organisational membership and information networks appeared to have a positive influence on the development of marine adaptation plans (Fig. 5). In total 35 councils were members of organisations that had as a stated aim the facilitation of local adaptation to climate change (this did not include membership of state council associations, to which all councils compulsorily belong). Most councils that were voluntary members of regional or international networks had marine adaptation plans.

In order to examine the relationships that exist between the multiple variables collected in this study, an exploratory multivariate analysis (non-metric MDS) was performed, producing a visual representation of council similarity (Fig. 6). This analysis creates a dimension for each variable, and plots councils along that dimension according to their similarity as measured by that variable. Because this analysis contains more dimensions (variables) than can be visualised, it compresses all dimensions into a two-dimensional graph for interpretation. The distance between each of the points (councils) describes their similarity in terms of all variables. Blue vector lines show the axes of increase for each variable (dimension) on this compressed two-dimensional graph. In data sets where strong relationships between different variables are present, clear groupings of points occur either along one or more vectors, or according to symbol category (in this analysis – state). This data set displays no such patterns. This indicates that for every degree of plan sophistication there exists a large variation in terms of council size attributes such as spending, income and population. This demonstrates that the degree to which adaptation plans are developed is decoupled from council size and access to resources in an important way. Taken together with the results presented above (Fig. 4) this suggests that while access to financial resources seems to have an impact on whether a council develops a plan in the first place, it does not seem to have an impact on how well developed those plans are.

4. Discussion

4.1. Progress

The results of this study indicate that Australian coastal communities are in the early stages of marine climate change adaptation. Despite local governments being positioned 'on the front line'

of responding to climate change, not all councils had incorporated marine drivers into their adaptation planning. Of those coastal councils who had considered marine drivers, many had not progressed beyond the understanding phase. This is mirrored in developed countries world-wide; actual intervention is rare, and where it is occurring, it is typically in the early stages [1]. Importantly, the presumed high adaptive capacity of developed nations such as Australia may not necessarily translate into adaptation action [22]. The various barriers that constrain the local adaptation process and result in this global pattern of inaction are the subject of continued scholarship [36]. This study provides some evidence of two widely reported barriers; a lack of resources and a lack of connections to relevant organisations that provide information and assist in communication. These two factors may be contributing to the slow progress of adaptation planning, and translating planning into action, in Australia's coastal communities.

The correlation between financial rate base and planning on marine climate change adaptation found in this study indicates that access to adequate funds is an important prerequisite for progress. Councils may be more likely to act if their financial throughput is above a certain threshold, with financially smaller councils unable to manage the redirection of funding away from other activities. A lack of resources, whether absolute or perceived, may limit actors that would otherwise progress adaptation [44]. However, the ordination of councils according to their attributes demonstrated that when variables relating to the sophistication of plans are examined, income is no longer an important determining factor. This suggests that resources are only important up to a point. Once councils have enough resources to begin developing plans, other factors not examined in this study may become more significant. Certain attributes of council staff such as level of education and specific climate change adaptation training, as well as institutional culture, have emerged as important enablers of action in other developed countries [6]. Additionally, the presence of a champion in the council or nearby in the social or political landscape can be crucial to the development and progress of adaptation [41]. Champions or 'god-fathers' are respected senior figures that provide the support necessary for innovative projects to transcend the managerial and organisational aspects of their institution that are barriers to change [42]. Finally, the level of climate change impact being felt (or perceived) in that local area may have a motivating or legitimating influence on adaptation actions. For instance, it would be expected that councils located adjacent to marine climate change hotspots

[25], where changes are clearly observable [27,28], would have a greater impetus to adapt to the impact of changing SST. Given the large disparity in coastal climate change impacts across the Australian continent, these localized observed impacts may be more important in explaining differences in action among councils than in other, more homogenous and less expansive countries. However, the small sample of municipalities in the current study that are in climate change hotspots does not provide enough data to investigate correlation between observed local change and adaptation action.

Effective communication, particularly between and across different levels of government has been identified as a major barrier to the coordination of effective adaptation action within European countries [4]. An aid to overcome this may be participation in adaptation-focused networks, which emerged as being closely linked with the occurrence of marine adaptation plans in this study. Participation in adaptation-focused networks seems especially pertinent in regional initiatives that link several local governments in a geographical area. Regional Organisations of Councils are voluntary partnerships between several (usually neighbouring) councils in a region, dedicated to cooperatively pursuing certain agendas by sharing resources, information and responsibilities across jurisdictional boundaries. Many Regional Organisations of Councils have developed into sophisticated regional governing networks [34]. Some have taken up the challenge of regional climate change adaptation, and serve as the hub for the development of member council adaptation plans. This may be particularly important in advancing adaptation if the socio-ecological system of concern functions at a larger spatial scale than local government areas [36]. In this circumstance functional relationships between councils will be crucial to avoid serious barriers [8].

4.2. A narrow breadth of focus

Councils generally display a narrow view of climate driven change in the marine environment in terms of both drivers and impacts. Most councils focus solely on sea level rise with an obvious lack of accounting for the multiple drivers involved. Given the wide range of impacts for coastal communities associated with the effects of increased sea surface temperatures and ocean acidification on marine ecosystems, this appears to be a major gap in Australia's overall preparedness for predicted change. Similarly, few councils had plans to adapt to the economic aspects of marine climate change; a trend noted throughout the developed world with adaptation overwhelmingly related to transportation, infrastructure, and utilities sectors – areas where investments have a long lifespan [22]. In this study all 38 marine adaptation plans involved some mention of infrastructural adaptation, while only 5 also involved economic adaptation. For coastal communities, impacts on livelihoods through changes in fisheries and tourism are likely to be significant, yet this remains a neglected area in council adaptation plans. The reasons for this could be the intangible nature of predicted impacts and the adaptation required. In addition, the comparatively strong incentives for action that are associated with sea level rise seem to be lacking for these more intangible impacts.

While the results of sea level rise impact assessments are relatively simple to translate into council policy, much of the research surrounding the impact of climate change on marine based livelihoods does not provide tangible predictions [2]. Instead, the emphasis is on unpredictable system behaviour, where feedbacks, thresholds and nonlinearities inherent in these systems produce unexpected outcomes (e.g. [30]). Responding to sea level rise is fairly straightforward with the set of management tools commonly used by councils (e.g. rezoning), and as evidenced in this study, this is how councils are proceeding. Other aspect of marine climate change adaptation (especially where dynamic socio-ecological systems like fisheries are involved) explicitly

require the use and sometimes the development of new management tools. This includes building adaptive capacity [33], developing institutions and instruments for reflexive and adaptive management [5], and building and diversifying the livelihood asset base of the community [2]. Knowledge of ways to operationalise resilience is available [13], yet it seems these types of approaches have not yet been widely adopted by councils.

While councils are positioned on the 'front line' of implementing local change, there seems to be an ambiguity to their involvement in adaptation activities. On one hand there is the well-established legal and institutional impetus to properly manage their own assets and responsibilities in the face of change, and on the other is the relatively recent high-level directive of their role in providing leadership in adaptation. The former may be a more immediate incentive for councils. In Australia, many councils have expressed concern over their legal obligations to manage climate change impacts, and the potential for legal action to be brought against them [39]. Australian councils face legal liability if they have unreasonably failed to take into account the effects of climate change in their service, planning and development activities [19]. Effectively, this leaves them responsible (and open to liability) for tangible impacts, but not for less tangible impacts such as those reported for ecosystem change. Responsibility may play a key role in decision making for councils, especially in prioritisation of actions. For example, Mandurah, WA, included information on the council's level of responsibility for each adaptation option alongside levels of risk and urgency in the commissioned assessment [43] on which their adaptation plans are based. Aspects of marine climate change adaptation that are clearly the responsibility of councils (legally or otherwise) may be receiving the bulk of what resources are available, while other aspects of adaptation, where responsibility remains ambiguous, may be falling by the wayside.

4.3. Adaptation as a uniquely local process

From the perusal of council documents it is clear that every situation will be qualitatively and quantitatively different; each problem unique; the focus of adaptation, the stage of development of plans and actions different; the purposes varied (e.g. some aimed at determining vulnerabilities, others aimed at determine future options, others aimed at specific actions); and each system typologically different and of different spatial extent. Councils are not equivalent, and the process of adaptation will likewise be unique, therefore councils will necessarily progress at different rates. More important is the quality of the process, which rests heavily on the reasoning used in decision making. The basis on which these decisions are made is the locus of adaptive success. Having robust criteria that take into account both the dynamic nature of the socio-ecological system in question, and the seemingly obvious but often unacknowledged requirement that adaptation plans themselves must necessarily be 'adaptive', can help ensure that action taken is appropriate in the long term. Key aspects of this process take place during closed meetings and communication and form part of the social and political context in which all council processes are embedded.

5. Conclusion

No other study has carried out a comprehensive assessment of climate change adaptation planning amongst coastal councils around Australia. These findings give insight into the current progress of adaptation and the consideration of marine climate change drivers nationally. The lack of consideration of the multiple drivers involved in marine climate change by councils currently in the understanding phase may represent a serious problem, as resulting plans will fail to cover the full breadth of potential impacts. Similarly, the economic

impacts of marine climate change are likely to have significant future implications yet may fall into an 'adaptation gap' because they are not a clear responsibility of councils and also somewhat removed from State and Federal responsibility. The future implications of these existing gaps are of national significance, and may be a feature of the adaptation challenge for developed countries globally. It is clear that councils with a more sophisticated understanding of the problems facing them are likely to have more encompassing responses, and are much more likely to develop Robust Strategies (sensu [30]) that minimise harm from climate change impacts spreading to other sectors and assets. Continued monitoring and reporting, as well as in-depth studies of the process itself, will ensure that gaps are identified and adaptation efforts are kept aligned with current understanding.

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