Climate Services Transformed: Decision-Making Practice for the Coast in a Changing Climate

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Climate services play an important role in informing decision makers about how to reduce the impact of climate-related hazards, by building capacity through access to relevant data and information globally and regionally. Different types of climate services include long-term warning systems, projections, monitoring/triggers and signals, risk evaluation tools, and behavior change tools. However, climate services are often promoted as "improving uptake" and "translating and communicating science" This framing, which assumes that climate services are developed by scientists and "provided" to users, has limitations for decision makers designing actions to address changing coastal hazard risk driven by sea-level rise. Acting upon the IPCC 1.5 Degree Special Report imperative for urgent actions to reduce exposure and vulnerability at the coast will require a transformation in the way climate services are developed and delivered, in tandem with an understanding of the decision-making and policy context. Tools and policies must explicitly address deepening uncertainty and changing risk over long timeframes. Their use also must be compatible with the jurisdiction's institutional frameworks and decision-making practice and relevant to user needs as changing risks unfold. Attention to both short- and long-term decisions are paramount to avoid lock-in and path dependency of decisions taken today, and to ensure relevance for the timeframes of investments in infrastructure and settlements. This requires actionable science and usable tools developed through multi-disciplinary efforts by scientists, co-producing them with decision agencies and communities. We give examples of different types of climate services developed with users and draw out some universal lessons learned in developing and applying them in New Zealand.

Keywords: climate services, sea-level rise, coastal hazards, adaptive planning, coastal flooding, policy

INTRODUCTION

In 2011, the World Meteorological Organization issued a global framework for climate services focused on assisting decision makers. The framework envisaged that the development of climate services would involve engagement between users and providers and would lead to a reduction in the impact of climate-related hazards and an increase in the benefits from benign climate

conditions. Inherent in the framework was the building of capacity, and open access to relevant data and information globally and regionally, resulting in a shift in risk reduction (Hewitt et al., 2012).

However, the literature reports that in UK and USA the public does not feel well informed about, and has difficulty understanding sea-level rise (SLR) (Thomas et al., 2015; Covi and Kain, 2016), despite ample evidence of SLR causing coastal flooding now, the low uncertainty bounds around SLR to 2050, and the current and projected impacts of SLR on people and their assets (Kulp and Strauss, 2019; Paulik et al., 2020). A New Zealand study confirmed these findings (Priestley et al., 2021) and showed that the public mistakenly overestimates the scientifically plausible amount of SLR by 2100 and incorrectly identifies melting sea ice as its primary causal mechanism.

A review in 2016 of lessons learned and future prospects for climate services (Brasseur and Gallardo, 2016) highlighted that there was insufficient awareness by stakeholders of their vulnerability to climate change, a lack of relevant products and services, and inappropriate product formats and delivery mechanisms. In a paper focusing on SLR, Hinkel et al. (2019) highlighted the lack of systematic analyses of users' needs, in particular, in different decision contexts and the users' level of risk and uncertainty tolerances. The principal reason for these disconnections between climate services and users, was a "top down" framing of climate services by those providing them, on the assumption that users did not understand the contextual issues – creating a disjunct between science outputs and decision-making needs and outcomes. Furthermore, there was a lack of understanding by scientists that their users and requirements were diverse, and that a range of formats and products were needed. A tension was highlighted between the different timeframes of the scientists and users and whether the analytical tools available (predominantly statistical and projections) could provide the certainty that decision makers say they need, within the institutional decision and legal frameworks in which they operate. Users typically work within a context that demands certainty which is often reflected in short-term and reactive decision-making processes. Lastly, the delivery mechanisms were not tuned to user needs. The 2016 review identified the need for a more nuanced architecture for climate services with attention to tailoring climate services to different users and delivering climate services at difference scales – global, national, and subnational. Furthermore, it highlighted the need for more diverse teams producing climate services and distributing and communicating the products. The review highlighted the need to build the capability of users and scientists in designing policies to reduce the risks of climate change and develop the enabling conditions necessary for climate resilient decisions, such as legislation and funding mechanisms, that support the implementation of policies.

The current focus on "improving uptake" and "translating and communicating science," assumes a business model where climate services are developed by scientists and "provided" to users (Cavelier et al., 2017). This approach assumes that "client" needs have been assessed and that services provided will realize those needs. It can also follow a "deficit model" approach to science communication (Irwin, 2014), where knowledge holders (in this case scientists) assume that providing accurate and up to date information to users (correcting their "knowledge deficit") is enough to ensure rational decision making with regard to climate risk.

This approach has severe limitations for decision makers assessing climate risks and designing actions to address changing coastal risks from sea-level rise, for example. In their paper on managing the risks of SLR, Kopp et al. (2019) discuss the need for usable science to inform decision making that must address long lag-times, irreversible losses, and deep uncertainty. For intra and intergenerational decisions to be made at different spatial scales, they stress the importance of multidisciplinary understanding across natural and social sciences, engineering, decision science, and political economy.

In New Zealand we have found that the factors discussed by Kopp et al. (2019) are necessary for climate services to address uncertainty and ongoing changing risk and enable actions to be taken pre-emptively, to avoid and reduce the worsening impacts of SLR. For example, this understanding informed the move to provide SLR projections as increments of SLR (Stephens et al., 2017), rather than specific projection scenarios. It has enabled SLR to be directly linked to local adaptation thresholds (Kool et al., 2020). This approach enables coastal hazard and risk assessments to be scenario-neutral, rather than having to make decisions on what RCP to use. This facilitates a direct line of enquiry by stakeholders to what the adaptation thresholds might be in different parts of low-lying localities. Scenarios for SLR can then be used to bracket the timing of the adaptation threshold and enable stress-testing of the lifetime and efficacy of short-term actions and longer-term adaptation options (Stephens et al., 2017)[1].

If the institutional frameworks and decision-making practice are compatible with the problem space (change and deepening uncertainty), both short- and long-term decisions can help avoid lock-in and path dependency (Haasnoot et al., 2013). Integrating the timeframes of investments in infrastructure and settlements can also assist (Kool et al., 2020). Multi-disciplinary efforts by scientists working together closely and co-productively with decision agencies, their professional advisors, and communities enables knowledge acquisition for developing a range of approaches and understanding values and preferences. However, Hinkel et al. (2019) point out that the preferences of users may not always lead to good outcomes, due to biases, partial knowledge, and conventions.

Here, we present different types of climate services such as long-term warning systems, projections, monitoring/triggers and signals, risk evaluation tools, and behavior change tools, illustrating them with New Zealand examples, including a red-alert tide calendar to pre-warn of potential coastal flooding days in low-lying areas; sea-level rise exceedance nomographs; serious games to embed understanding of uncertainty and changing risk that can bridge to the application of dynamic adaptive pathways planning (DAPP) (see section "Dynamic Adaptive Pathways Planning"); national-scale application of a risk-evaluation tool to

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[1] Refer Table 1 and Figure 5 of Stephens et al. (2017)

identify what is at risk and its cost; information defining asset exposure and flooding likelihood relevant to the banking and insurance industries as they enter the new transparent disclosure regimes; and lessons from the application of DAPP processes. From these examples grounded in real-world practice, we draw out universal lessons learned in developing and applying them.

WARNING OF COASTAL FLOODING

Coastal flooding is a major global hazard with records of historical events back to 1200 AD killing hundreds of thousands of people and causing billions of dollars of damage to property and infrastructure (Pugh, 1987; Lagmay et al., 2015; Needham et al., 2015; Haigh et al., 2016). Globally, it has been estimated that up to 310 million people are already exposed to a 1 in 100-year flood from the sea (Jongman et al., 2012; Hinkel et al., 2014; Muis et al., 2016). In New Zealand, this includes 72,000 people, or 1.5% of the population (Paulik et al., 2020). The number of people exposed to such flooding will markedly increase globally. It has been estimated that 0.2–4.6% of global population will be flooded annually under 25–123 cm (RCP2.6–RCP8.5) of global mean SLR without additional adaptations (Hinkel et al., 2014). Furthermore globally, 630 million exposed people currently live on land below projected annual flood levels for 2100 (Kulp and Strauss, 2019). Flooding can occur during very high tides (Ray and Foster, 2016), or during storm-surges and any associated wave overtopping, combined with higher tides when low atmospheric pressure and strong winds drive the sea onto land (Tebaldi et al., 2012). Sometimes these processes can combine to produce very high storm-tides. Improved understanding of extreme sea level and coastal flooding events and the role of higher spring tides (Stephens et al., 2020) and their consequences is therefore important.

To understand and manage this risk exposure, government agencies, environmental and emergency managers and the insurance and banking sectors, all require knowledge of the likely frequency and magnitude of extreme storm-tide and wave overtopping events, how they compound with multiple drivers, and their clustering in time and space. Forecasts of the timing and magnitude of coastal hazards allow coastal or emergency managers to design appropriate responses, so they can significantly reduce risk and warn the communities affected. Two simple decision-relevant examples used in New Zealand are the "red-alert" tide calendar and sea-level exceedance nomographs.

The "Red-Alert" Tide Calendar

Stephens et al. (2014) was developed to support coastal management decisions (see **Supplementary Material**). It is a simple and practical tool that clearly communicates dates of higher-than-normal high tides to indicate when low-lying land is particularly vulnerable to coastal flooding (**Figure 1**). The red-alert tide calendar works well in regions where the variability of extreme sea levels is influenced substantially by the height of high tide (as in important precursor of for coastal flooding), rather than just by storm surges and associated waves) – such as in regions that do not experience tropical cyclones (hurricanes).

In this respect, tides dictate the occurrence of extreme coastal sea levels over much of the world (Merrifield et al., 2013; Rueda et al., 2017; Stephens et al., 2020) with storm surges being a secondary effect. On that basis, the annual or 3 monthly red-alert calendars highlight the highest tide days so users can watch for adverse weather forecasts (onshore winds, low barometric pressure, wind waves and swell) leading up to the red-alert tide days (Stephens et al., 2014). The calendar is based on the premise that most extreme storm-tides are driven by more common moderate storm-surges combined with high perigean-spring ("king") high tides, in tide-dominated locations, for example, within the United Kingdom and New Zealand (Haigh et al., 2016; Stephens et al., 2020). Extreme storm-tide elevations in New Zealand are highly correlated with and linearly related to mean spring high-tide elevation, noting spring-tide ranges (meso-tidal) at main coastal cities/towns vary from 1.4 to 3.8 m (Stephens et al., 2020). Climate-change impacts on extreme storm surge and waves are predicted to be modest in the New Zealand region (Cagigal et al., 2020).
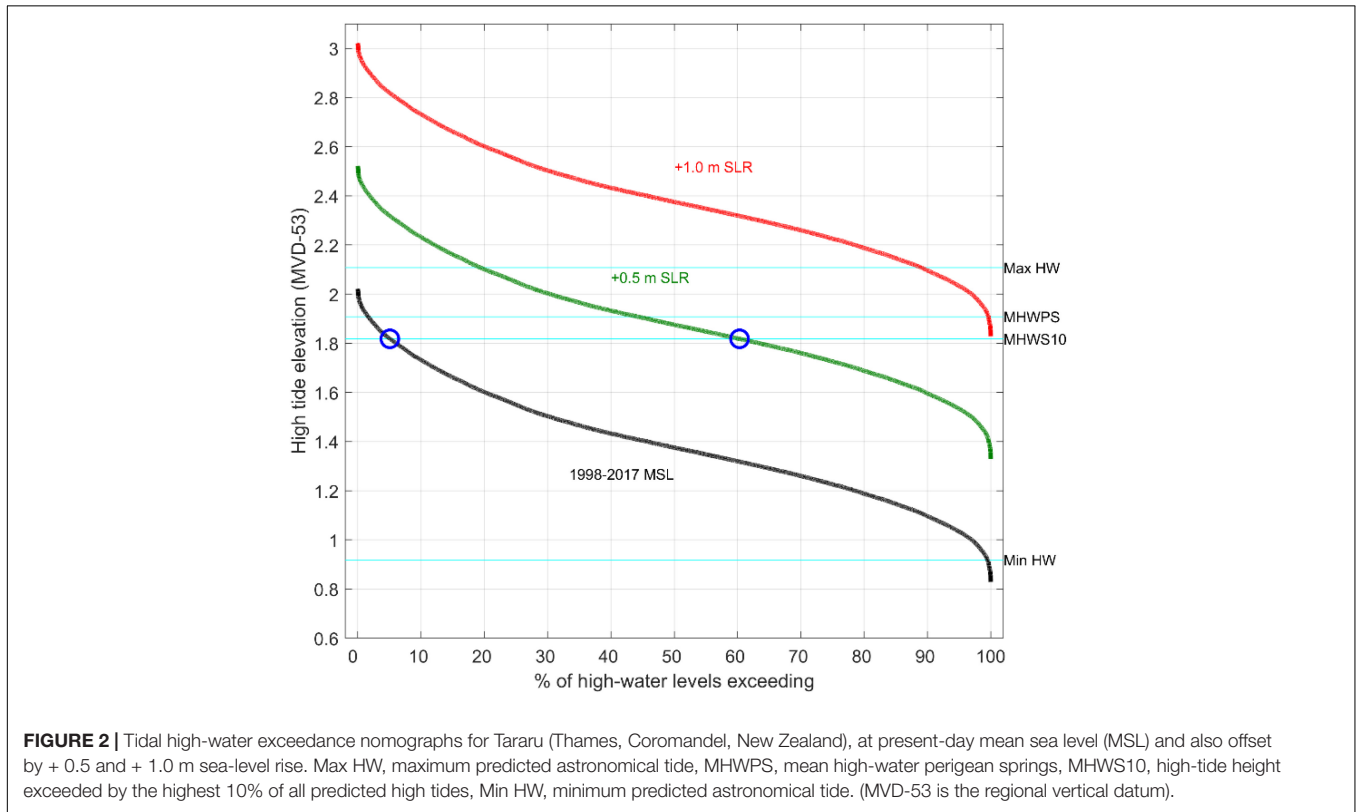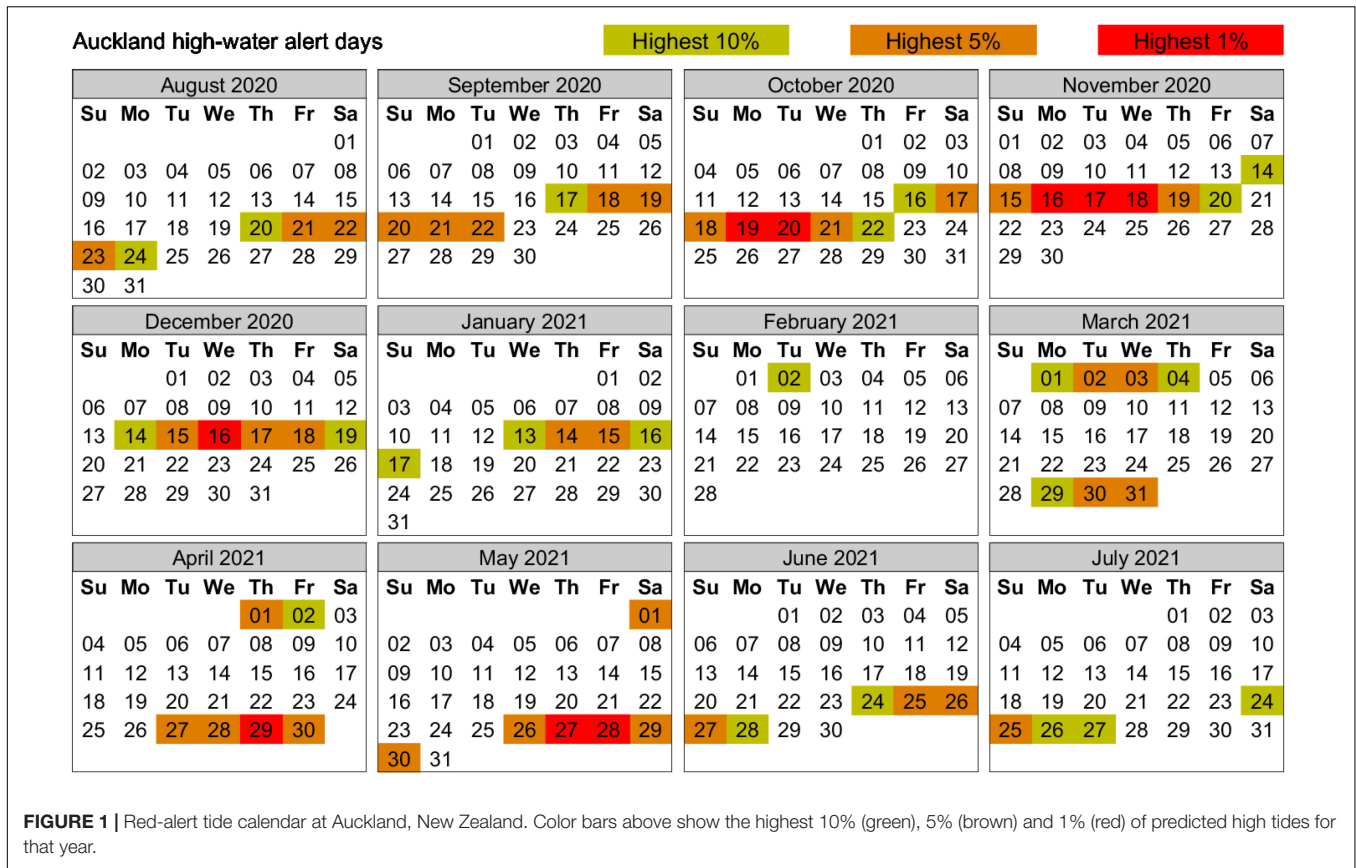
Tides are routinely predictable using tidal harmonic analysis of sea-level gauge records or global ocean tide models (Ray, 1999; Matsumoto et al., 2000; Egbert and Erofeeva, 2002; Lyard et al., 2006). This means that red-alert tide calendars can be tailored and applied regionally and used as an early warning system for increased risk of coastal flooding in low-lying areas relative to local spring tide levels.

Red-alert tide calendars are highly visual and easily interpreted, and do not require technical expertise or interpretation of large amounts of data or text (**Figure 1**). Providing several alert thresholds allows users to use their experience to "tune in" to the calendar, by correlating the alert level with the severity of past local consequences. Thus, the high-water calendar can be used, for example, by local fishers making decisions on where to moor vessels, or by emergency managers, knowing that even a moderate swell event could cause significant flooding if it coincides with a red-alert date. The high-water calendar is easily updated and displayed on a web site or can be sent electronically for local distribution. There is demand now to upload these calendars months ahead of a new calendar year. The red-alert tide calendar has also spawned a citizen science programme in Auckland (New Zealand) through the King Tides Auckland Initiative (2020)[2] which is aligned to the global network of King Tide Projects (e.g., Australia, Hawaii, Oregon). This initiative focuses on public engagement and awareness around the highest red-alert days each year, encouraging citizens to "snap the coast" at the designated time of the high tide and upload the photograph to the public web site. This forward-thinking public engagement initiative allows both scientists and citizens to utilize these red-alert tide days and visualize the impacts rising sea level may have on their communities in the future (Román-Rivera and Ellis, 2018).

Sea-Level Exceedance Nomographs

Are another simple tool for visually demonstrating the effect of SLR on the frequency of present-day high-water thresholds

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[2]Retrieved from: https://auckland.kingtides.org.nz/

FIGURE 1 | Red-alert tide calendar at Auckland, New Zealand. Color bars above show the highest 10% (green), 5% (brown) and 1% (red) of predicted high tides for that year.

FIGURE 2 | Tidal high-water exceedance nomographs for Tararu (Thames, Coromandel, New Zealand), at present-day mean sea level (MSL) and also offset by + 0.5 and + 1.0 m sea-level rise. Max HW, maximum predicted astronomical tide, MHWPS, mean high-water perigean springs, MHWS10, high-tide height exceeded by the highest 10% of all predicted high tides, Min HW, minimum predicted astronomical tide. (MVD-53 is the regional vertical datum).
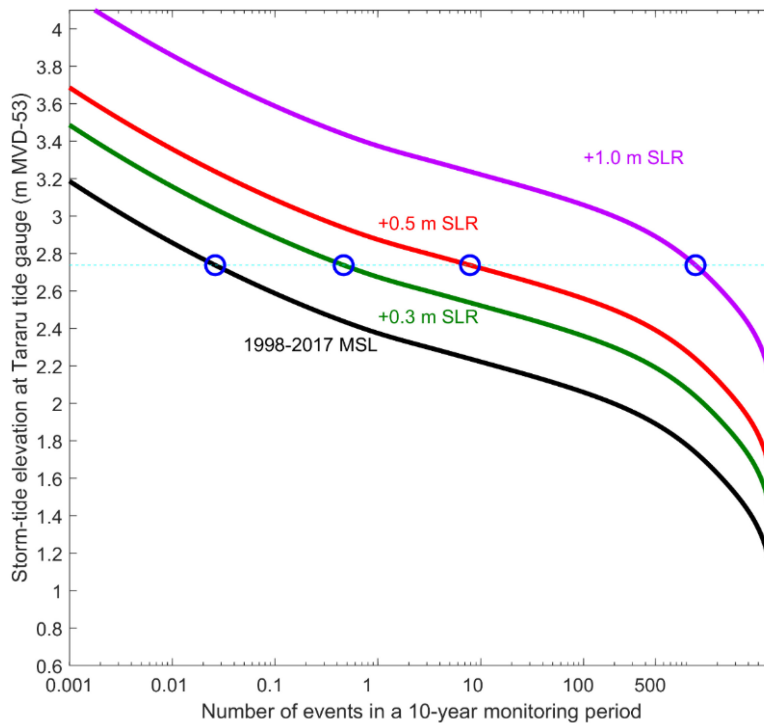
FIGURE 3 | Change in frequency of storm-tide flooding with SLR at Tararu, Thames, Coromandel, New Zealand. The nomographs are derived by transforming the high-water exceedance curve in **Figure 2** following methods in Stephens et al. (2018).

(**Figures 2**, **3**). High-water exceedance nomographs can be used to assess the increase in the frequency of high waters exceeding present-day thresholds for different rises in mean sea level, under the assumption that future modification to tidal characteristics is relatively small (Bell, 2007, 2010). This is reasonable for open coast locations as an approximation to convey the key message of changes and onset of semi-permanent high-tide inundation. However, the nomographs should be used with caveats, particularly in estuaries and shallow semi-enclosed bays, where tidal ranges may change significantly either way, depending on sedimentation rates and morphology, which require detailed modeling to ascertain the changes over time. In the case where tidal changes over time are modest, the entire present-day high-water exceedance curve can be raised vertically by different values of SLR. Rueda et al. (2017); Stephens et al. (2014), and Stephens et al. (2018) showed that tide-dominated coastal flooding regimes will be more sensitive to SLR influenced by increasing frequency of extreme storm-tide events, compared to storm surge-dominated regions exposed to hurricanes, typhoons or tropical cyclones. This is particularly the case in New Zealand, where the tide is the key determinant of extreme storm-tide levels or wave overtopping. Sea-level exceedance nomographs have been found to simplify communication for users where a 0.5 m SLR would result in 60% of all high tides exceeding the present-day spring-tide mark (MHWS-10) (**Figure 2** circles), which is exceeded currently by only 10% of high tides. This assumes that changes in tidal characteristics with rising sea level are not markedly different, as

indicated by Devlin et al. (2017). Even higher percentages of high-tide exceedances will occur, relative to present-day spring tides, in areas with smaller tide ranges (micro-tidal regions), for a given increment of SLR (Bell, 2007, 2010).

Red alert tide days, rising high-tide exceedance and flood frequency nomographs present long-lead-time warning information in a way that is readily usable. In particular, the red-alert tide calendars were tested and revised with a range of users over a period of a few years, largely at local government levels of decision making, with users' input reflected in the alerts and thresholds finally adopted. The simplicity of the tools, which each convey a single idea on potential and increasing frequency of coastal flooding, is shown in **Figures 1–3**. This has engendered increased confidence by users in the application of the science underpinning the calendars and nomographs, based on feedback from users, particularly in understanding the increasing frequency of coastal flooding as the first tangible impact of SLR.

BUILDING AN INTEGRATED UNDERSTANDING OF COASTAL FLOODING AND DECISION MAKING

Climate services are often provided as discrete pieces of information for an area at risk or particular type of hazard. However, adaptation to climate change and increasing capacity to manage climate and other risks, reinforces the need for sets of information relevant to different stages of the decision-making

process. This would support a broader array of risk management planning and implementation activities, beyond traditional climate services (Lawrence et al., 2019a; Jacobs and Street, 2020) for example, where changing risks have significant consequences and where they are foreseeable. It would also address the problems when information on climate change hazards, their impacts and risks into the future become intertwined in ways that create barriers for developing alternative options/pathways for adaptive management. For example, when the hazard is merged with the risk. The latter is an expression of what is exposed, its vulnerability, and agents and communities' preferences. The former is a technical analysis, while the latter is deliberative and political. Furthermore, the sheer volume of information (quantitative or quantitative) that individuals or groups are asked to assimilate in many assessments can generate default qualitative decisions that lead to mal-adaptive actions that can lock in current risk and make it harder and costlier to address as the climate changes intensify. Three examples of climate services have been developed and/or applied in New Zealand that can help address these outcomes – serious games, DAPP and bespoke services for the finance sector.

Serious Games

Are designed to educate, train, and inform (Michael and Chen, 2005) and can be computer or board based. They have been developed and used globally across many domains of interest including military strategy, health planning, public policy and public awareness raising. Their use in climate change decision-making processes has helped to build understanding of risk and develop capacity to act that is robust across many different potential outcomes (Lawrence and Haasnoot, 2017). Serious games enable complex strands of information from different sources (e.g., technical values, objectives, changing risk over time) to be considered systematically, by testing how different outcomes can be achieved in the face of the uncertainty presented by a changing climate and associated hazards (Flood et al., 2018). While serious games are abstractions from reality and as such enable place-based interests to be suspended, they retain the central decision-making tensions present in the real world, by creating a simplified decision-making experience that can embed learning for real-world decision making.

Four different types of serious games have been developed in New Zealand as climate change services (**Table 1**; see **Supplementary Material**).

(a) Simple serious games where the player makes the decision in the absence of other groups or players – the player acts toward their own desired outcomes with feedbacks on the choices made, from the game.

(b) Games where there are other non-player characters or groups (of players) representing other interests which seek to influence the choices – at different levels of complexity not tied to a specific place.

(c) Bespoke games designed for specific locations, people and sets of decisions.

(d) Computer simulated games with climate model data driving the feedback on choices made by single or many players.

All games, however, are designed using the same set of steps (**Figure 4**). What varies is the level of detail provided through the game to the participants, the complexity of the storyline and whether they are computer simulated. Tier 1 games are short games (5–10 min) designed to convey a set of simple messages using a simple storyline and a generic location. They are co-designed with technical partners and key stakeholder groups. They do not need detailed numerical data and rely on abstracted scientific knowledge. An example is the NIWA flood adaptation and SLR game[3]. Tier 2 games use more complex decision questions and have nuanced storylines that are supported by more detailed data and information. Such games can be placed-based and constructed from quantitative data, but the presentation of the information remains simplified to be more accessible. In the Coastal Adaptive Futures tier 2 game (Blackett et al., 2019) community representatives contributed real-world issues relevant to decision- making context. While tier 1 and 2 games provide learning and dialogue opportunities, tier 3 games are bespoke, for supporting real-life decision making in place. The Marae-Opoly Game is a tier 3 game designed for a particular place, with real alternatives, finances and used to support the development of DAPP (Colliar and Blackett, 2018) (see **Supplementary Material**).

These games build on the Te Ara River Game and Tainui Coastal Game developed in 2015 based on the Dutch Delta Game (Haasnoot et al., 2013)[4], the evaluation of their uptake (Lawrence and Haasnoot, 2017) and its application in the Hutt River flood risk management plan (Lawrence et al., 2019a). The games and their use with DAPP applications have motivated

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[3]https://niwa.co.nz/natural-hazards/our-services/serious-games-as-a-tool-to-engage-people

[4]https://www.deltares.nl/en/software/sustainable-delta-game/

TABLE 1 | Game complexity typologies.

Game	Type	Complexity	Characteristics
"Climate adaptation challenge"	Board game	Low	Simple narrative Generic location Simple range of options Individual player choices
"Adaptive futures"	Online game	Medium	Simplified narrative Generic location Individual player choices but influenced by non-player characters
"Marae-Opoly"	Board game	High	Complex place-based narrative Collective decisions Real place-based options Complex choices and feedback
"Tainui coastal game"	Computer-based game	High	Complex narrative Collective decisions Complex choices and feedback Plausible options

FIGURE 4 | Process for developing and testing serious games.
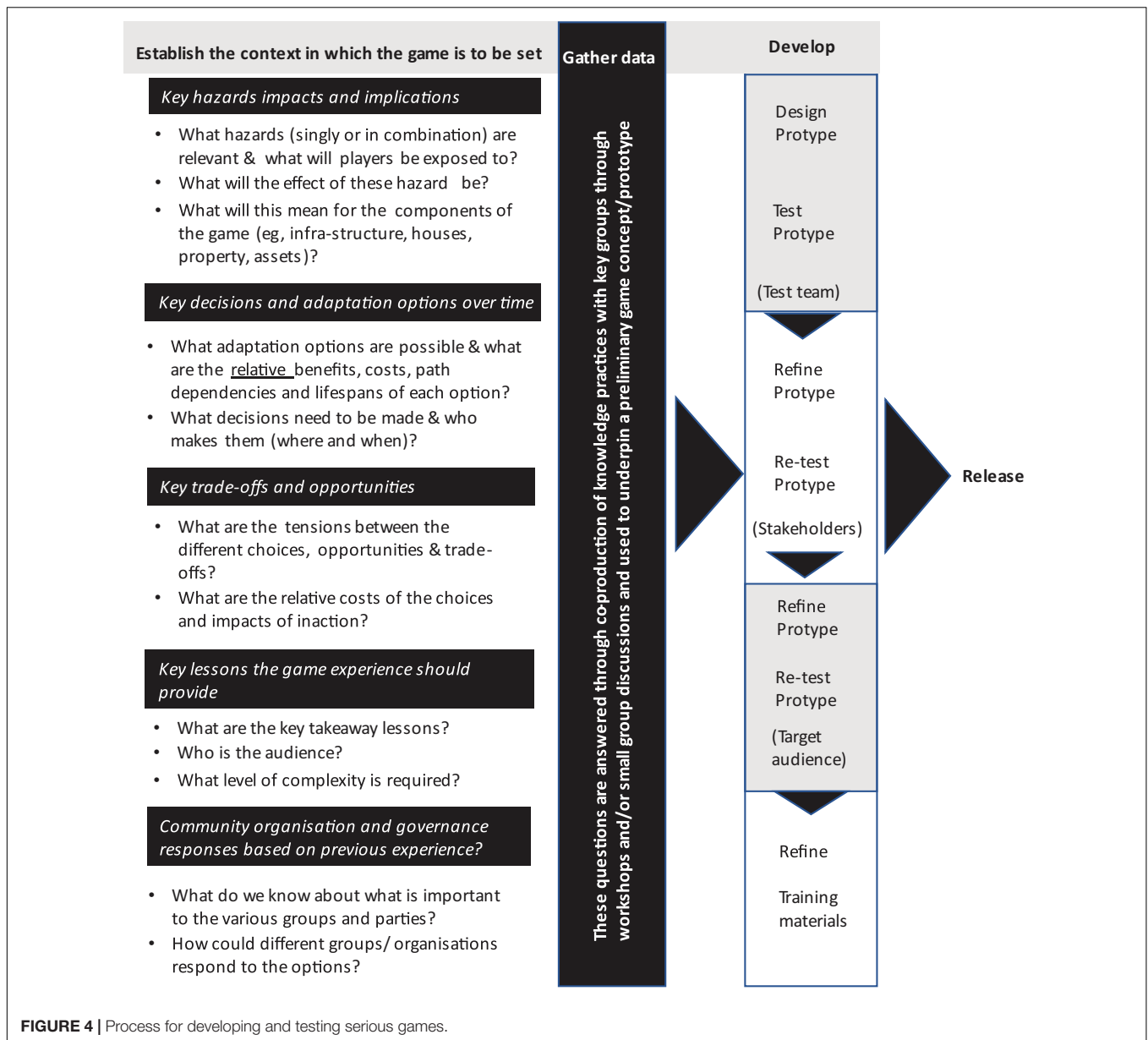
the development of signals and triggers for monitoring DAPP pathways by decision makers (Stephens et al., 2018).

For games to be effective in priming long-term thinking and adaptive action in a climate change setting, they require multi-disciplinary perspectives, and an ability to reduce and reframe complexity in a way that makes it possible to navigate choices over time (Simpson et al., 2021). Clarity of outcomes, values, objectives of different interests, options effectiveness, and costs and trade-offs are essential elements of any decision context. Since the information and expertise required will seldom be held in one knowledge basket, different disciplinary, value and cultural perspectives are necessary to inform the assessment of climate change risk (Blackett et al., 2019). This changes the face of what we know as climate services, from discrete to integrated information and learning processes to support assessments.

For games to be effective as learning devices, understanding decision tensions relevant to the intended audience, is needed to capture enough of their life experiences and scenarios of the future, to generate a meaningful experience that can be robust over time as risks change. Our experience in developing and using games has been iterative as we test and refine their effectiveness in different settings (see tier 1–3 examples above). **Figure 4** shows the process employed to develop and test serious games with users.

Several examples (see **Supplementary Material** and **Supplementary Figure 1**) illustrate how serious games played in decision contexts can prime decision makers and communities to enable them to plan and adapt to changing climate risks. They generate learning about what climate change impacts could be, the changing nature of the risk to those affected, the limits

of different adaptation options and the values and preferences of other people and organizations. They do this by enabling thinking beyond the normal range of preferences in a setting where failure is hypothetical and leads to testing previously unconsidered or rejected strategies. By considering all aspects of the system at risk, serious games provide a simple way of looking at the whole system in an integrated way, by looking at the wider societal consequences of taking different courses of action over different timeframes and what it takes to implement an end objective that is highly challenging for current generations, such as managed retreat. Bespoke games, can be used to develop adaptation pathways, building from the options chosen in the game, or lead to the application of the DAPP planning process to build up pathway's options with signals and triggers of change between different pathways (Colliar and Blackett, 2018) as conditions change (see **Supplementary Material**).

By using games to experiment with different audiences and in different decision settings, those providing the climate services can learn how their information can be more relevant to different decision processes. For example, the long-term planning for a marae[5] threatened by SLR became a catalyst for a wider conversation about climate services, their funding, and responsibility for them and opened up the space to discuss how the wider community might benefit from short-term and long-term actions to adapt to sea-level rise.

The games applications highlighted the value of developing climate services with the affected agents and communities and challenged assumptions made about the ability of the users to apply the services received and source data and other climate information (quantitative and qualitative) in a usable form. They also enabled other tools to be used effectively, by increasing understanding of changing climate risk and enabling discussion of adaptation options when using DAPP in a way that embeds values and preferences into the decision outcomes.

Dynamic Adaptive Pathways Planning

Climate services took a turn toward adaptive risk management tools for decision making under changing climate conditions following Kwadijk et al. (2010), who demonstrated the value of shifting from a pressures/state/impact model for addressing sea-level rise, to an anticipatory tipping point model. Usability of climate services (Kopp et al., 2019) is at the center of the climate services in this paper. Usability, is a critical criteria for the design of any climate service. This implies that the information is robust across a range of futures and is relevant to the decision space of the users. But how can this information inform the decision process in a way that reduces the uncertainty and changing risk at the coast and facilitates engagement with stakeholders?

This is where DAPP can provide a decision process to integrate the climate information when assessing adaptation options and alternative pathways in the face of the accelerating, compounding and cascading climate change hazards and risk.

Dynamic adaptive pathways planning mirrors choices made on a metro map (**Figure 5**), testing each option for travel to a destination against different operating conditions over time

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[5] A Maori community meeting house

(scenarios). By making choices for short-term options where there is greater certainty of outcome, the DAPP can identify signals (warnings) and triggers (decision points) with enough lead-time to implement alternative options on the pathway chosen or to switch to another pathway to reach the objective. The process is based on the principle that there is uncertainty about the future in some respects and that locking in a particular pathway will result in path dependency from which it becomes more difficult over time to shift, due to the advancing hazard risk. Leaving options open in the future by taking short-term decisions that enable option/pathway change later, gives flexibility to reassess the options and chart a different course depending on how the future turns out. This iterative and adaptive process addresses both uncertainty of outcome and the rate of change. Its application in coastal and river flooding contexts is now well-tested in many locations globally (Haasnoot et al., 2013, 2018; Ranger et al., 2013; Kingsborough et al., 2016; Bloemen et al., 2019; Lawrence et al., 2019a).

The recent shift in approach for undertaking coastal mapping and risk assessments, toward providing SLR projections in terms of increments of SLR (Stephens et al., 2018), rather than specific projection scenarios referred to in the introduction, has enabled SLR to be aligned with local adaptation thresholds (Kool et al., 2020), thus allowing signals (to warn of changes in conditions) and triggers (for deciding on alternative options and pathways) (Haasnoot et al., 2013) to be integrated into coastal hazard and risk assessments by bracketing the timing of the adaptation thresholds and for stress-testing the shelf-life and efficacy of short-term actions and longer-term adaptation options using DAPP.

In New Zealand, the application of serious games with local government officials has led to experimentation with DAPP in real-life decision making (Lawrence and Haasnoot, 2017; Lawrence et al., 2019a) and the inclusion of DAPP as a primary adaptive decision-making process in the national coastal hazards and climate change guidance (MFE, 2017; Lawrence et al., 2018). Furthermore, this has spawned the tailored development of the DAPP, again in real-life decision settings at the coast (OECD, 2019), through development of signals and triggers for decisions based on the robust science that underpins the red tide alert and coastal flood frequency climate services and the development and application of real options analysis to pathways planning in fluvial and coastal flooding contexts (Lawrence et al., 2019a). A multi-disciplinary team within New Zealand and with international colleagues has enabled climate services to be integrated for application by decision makers.

Bespoke Climate Services for the Finance Sector

The New Zealand Government has introduced legislation for mandatory disclosures of climate-related risks by companies and financial institutions which comes into effect in 2023. It requires all banks, asset managers and insurance companies with more than NZ$1 billion in assets to disclose their climate risks, in line with the emerging global standard from the Task

FIGURE 5 | Adaptive pathways showing signals, triggers, and pathways.
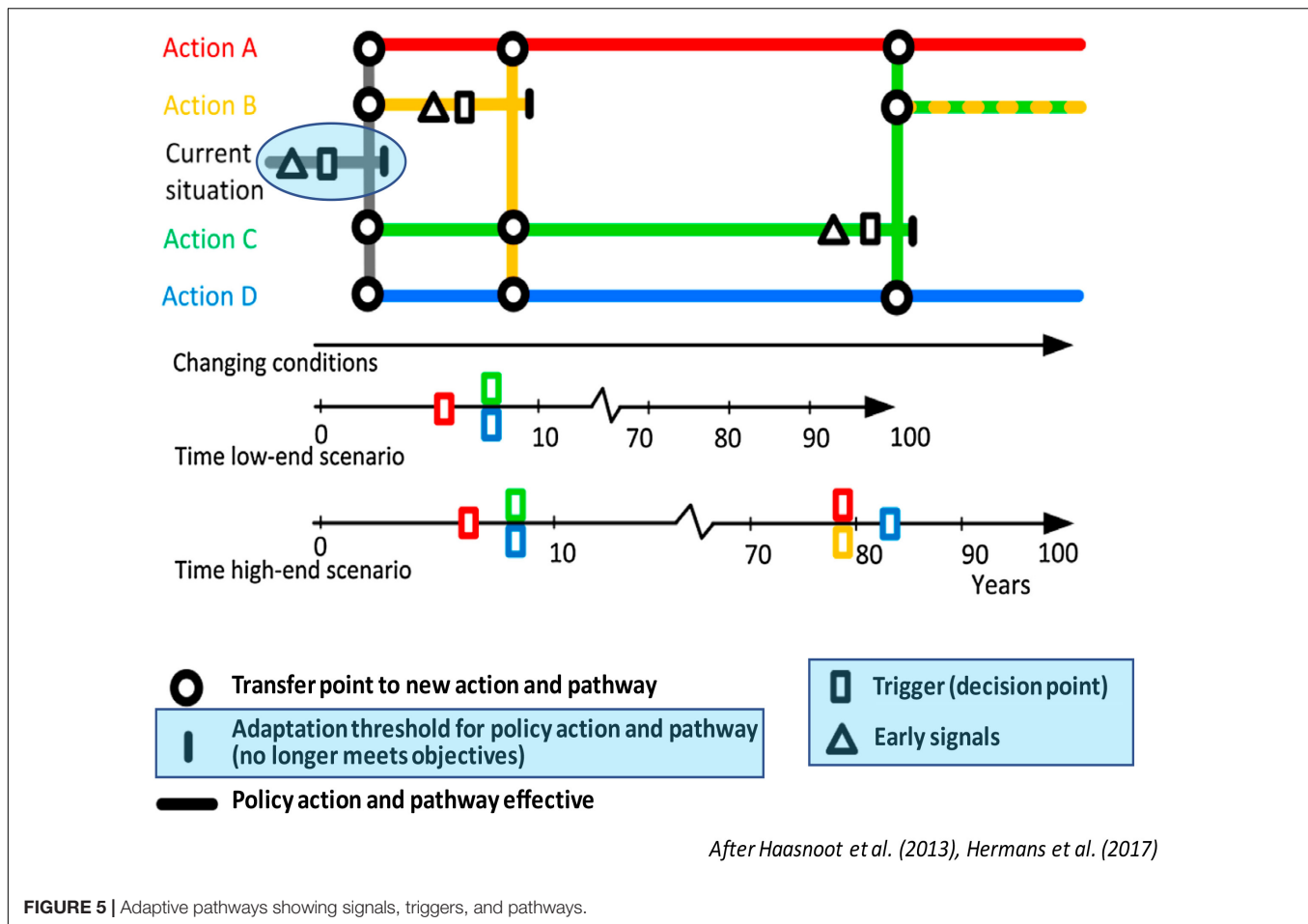
Force on Climate-related Financial Disclosures (TCFD). This will require banks to consider the transition, physical and liability risk when lending and offering insurance to households and small and medium size enterprises. This matters most to domestic real estate, which is the largest item on the balance sheet of New Zealand banks, and agricultural and small businesses. Figuring out what climate risks banks are exposed to is not a simple task. Banks and insurance companies will need to scale up their ability to estimate flooding risk from extreme rain, storms and SLR on residential housing[6].

The RiskScape tool (Schmidt et al., 2011) developed in New Zealand can help address TCFD requirements (**Figure 6**). RiskScape combines datasets of hazard, exposure (i.e., elements-at-risk), and vulnerability, in a state-of-the-art software engine that quantifies risk of exposure or impact at national- to local-scales (**Figure 6**). RiskScape has been used in New Zealand at a national scale to enumerate the built-environment land and assets, and their geometric quantities directly exposed to coastal flooding (Paulik et al., 2020). Paulik et al. (2020) evaluated a 1% annual exceedance probability (AEP) storm-tide levels and sea-level rise. A present-day 1% AEP storm-tide event is quite

large and rare, by definition, but will be exceeded with rapidly increasing frequency as sea-level rises (Hunter, 2012; Sweet and Park, 2014; Stephens et al., 2018). A 1% AEP event, when added to SLR estimates, provides suitable scenarios to meet New Zealand Coastal Policy Statement objectives that require coastal-flood hazards to be identified to avoid increasing risk over "at least the next 100 years" (DoC., 2010; MFE, 2017).

However, meeting TCFD requirements requires scenarios tailored to shorter-term decision making, typically ≤ 30 years which is the typical domestic real estate mortgage lifetime. Discussions with the banking industry indicate that a 10% AEP storm-tide flooding event is a more relevant event to model for TCFD requirements than a 1% AEP event – a 10% AEP event is likely to occur 3 times over a 30-year mortgage (although could occur more or less frequently depending on climate variability).

A key element of climate change planning is understanding the potential timing of impacts. Stephens et al. (2017) provided a table of the approximate years, from possible earliest to latest, when specific SLR increments (meters above the IPCC AR5 1986–2005 baseline epoch) could be reached for various scenarios of SLR for the wider New Zealand region – the table is included in national guidance for coastal climate change adaptation (MFE, 2017; Lawrence et al., 2018). **Table 2** provides SLR projections designed to meet TCFD requirements out to 0.3 m SLR. For

FIGURE 6 | RiskScape model framework applied by Paulik et al. (2020). ESL100 = 100-year average recurrence interval extreme sea-level. DEM = digital elevation model. Adapted from Paulik et al. (2020).
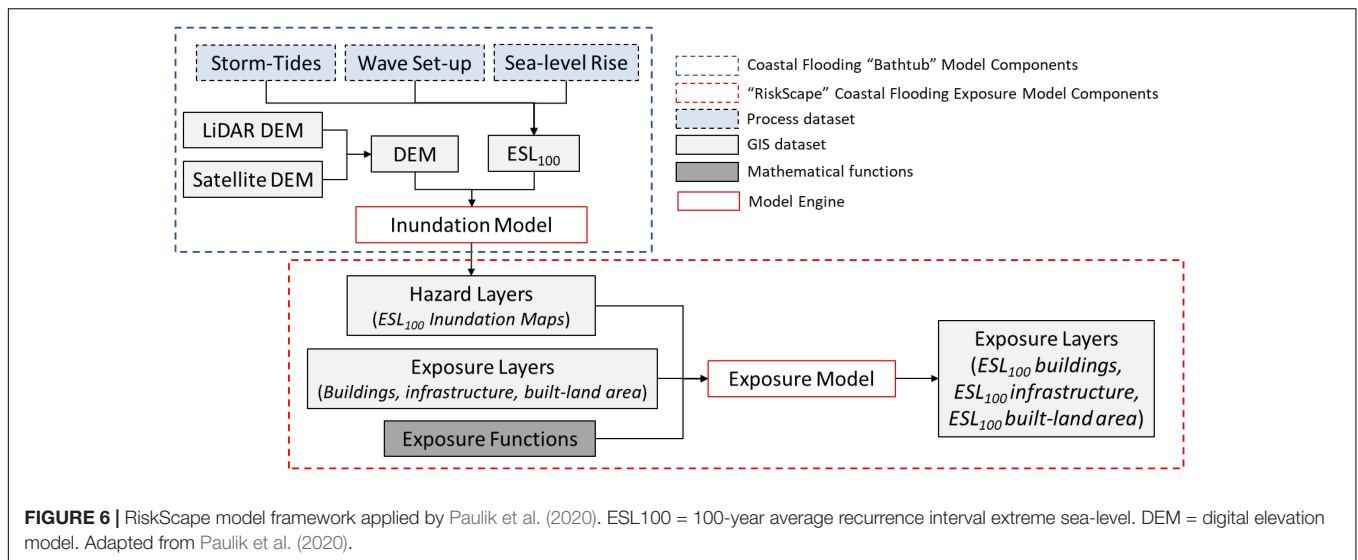
TABLE 2 | Expected year to reach 0, 0.1, 0.2, and 0.3 m SLR relative to 2020 base year, for fast and slow SLR scenarios Slow SLR scenario is RCP 2.6 median.

Scenario	Present-day MSL	Present-day MSL + 0.1 m SLR	Present-day MSL + 0.2 m SLR	Present-day MSL + 0.3 m SLR
SLR(m)	0	0.1	0.2	0.3
Year SLR reached slow SLR	2020	2040	2062	2082
Year SLR reached fast SLR	2020	2033	2044	2054

Fast SLR scenario is RCP 8.5 upper 83rd percentile (H+) (MFE, 2017). MSL, mean sea level. Source: Stephens et al. (2017).

a fast SLR rate [RCP8.5 H^+, MFE (2017)] 0.3 m is projected to be reached by 2054, which is slightly more than a 30-year mortgage lifetime from now – this will take longer under a slow SLR scenario.

DISCUSSION

Climate services are not an end in themselves. They are for motivating and supporting decisions which fit within the prevailing governance and institutional frameworks in each jurisdiction. The applications demonstrated in this paper have been applied to decisions for reducing climate change risks. Typically, hazard and risk reduction has been set in static institutional contexts. For example, a hazard is identified in one place at one time or as an event that happens and creates a disaster from which recovery and rebuild is the usual track to follow. Climate change challenges that approach. While extreme events will continue to occur, and some with greater frequency and intensity, hazards at the coast will exacerbate the risk by being ongoing (sea-level rise) for centuries even if emissions are reduced to achieve 1.5 degrees (Paris Agreement). SLR is already exacerbating the high tidal effects discussed above. Where there is a tidal footprint in groundwater,

water tables are rising and creating coastal flooding; this will continue and create an existential threat in many low-lying parts of the world.

These characteristics of climate change impacts reveal that for effective adaptive planning, new institutional arrangements and planning practice are required. To date planning and legal mechanisms to reduce climate change risks have proven inadequate (Lawrence, 2015), for example: warnings of flood risk on property titles; mixed jurisdictional authority between the two levels of local government has hindered regional planning which could have enabled territorial local government to prohibit further exposure in risk prone areas; and special legislation to increase housing development has allowed risk reduction provisions where they exist, to be sidestepped. This is despite national coastal hazards and climate change guidance that embeds DAPP and the New Zealand Coastal Policy Statement which requires councils to take a precautionary approach, including the place of managed retreat as an adaptation option. The New Zealand government is currently (June 2021) developing a Strategic Planning Act and a Climate Change Adaptation Act to provide the enablers for adaptation, such as, new funding and legal instruments to address existing land uses and managed retreat and the integration of DAPP and strategic risk management into the new statutory regime. Both climate services and the institutional arrangements must be in sync with the dynamics of change at the coast.

The on-the-ground experience presented here, demonstrates the type of climate services that are useful and effective for addressing the risks of climate change in coastal areas, in particular, for addressing the ongoing changing risks and the long-term uncertainties related to sea-level rise. These risks are changing rapidly, and physical and social thresholds are approaching. Decisions are being taken now that continue investment in at-risk coastal areas and expose more people and assets to harm. Developing climate services in isolation from users, and "selling" them as "services" confuses supply

with demand. It risks development of unusable services that can divert effort on adaptation to purely tweaking business-as-usual approaches. This has potentially significant maladaptive outcomes that will make adaptation in the future hard to implement and very costly.

Our experience is that it is extremely effective for applied researchers to work closely and on a regular basis with end-users who can spot gaps in the climate service knowledge or systems. This enables decision problems to be researched quickly, tested with the users and useful tools delivered for adaptation decision making. The benefits of the climate service, though, can take time for uptake. For example, the red-alert tide calendar was initially slow to be taken up, but then pressure built up from a range of users, wanting next year's calendar to use for coastal emergency management planning. The catalysts for uptake of DAPP approaches were: (i) a series of changes to New Zealand's resource-management legislation in 2004, 2010, and 2017 (requiring councils, when developing land-use plans, to have particular regard to the effects of climate change, develop 100-year strategies for adapting existing development and manage significant risks from natural hazards); (ii) by the publication of academic papers (Haasnoot et al., 2018; Stephens et al., 2018; Lawrence et al., 2019a,b) and policy reports and reviews which primed understanding through training and development of DAPP (Lawrence and Haasnoot, 2017); (iii) development of council climate change strategies (e.g., Greater Wellington Regional Council 2015)[7]; (iv) integration of DAPP in national coastal hazards guidance (MFE, 2017); and (v) a sequence of damaging coastal storms and floods in 2018. The role of the media in informing the public about climate change and SLR has also motivated political attention to the adaptation solutions space (Haasnoot et al., 2020). The process can be categorized as creating interest, increasing awareness, and experimenting in real-life decision contexts, through a reinforcing set of

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[7] Available at http://www.gw.govt.nz/assets/council-reports/Report_PDFs/2017.194a1.pdf

parallel activities to enable uptake of the climate services set out in this paper.

User relevance has evolved as an effectiveness criterion for the funding of national research. New Zealand has two research models that bring researchers and users closer together on climate service production. First, a consultation and involvement model funded for researchers and users to interact closely on decision-relevant research to fill knowledge gaps or develop decision tools that meet user needs Lawrence and Manning (2012) with a focus on smaller resource-poor councils or for research of general relevance across many councils. The development of the DAPP approach and the use of Real Options Analysis developed from this model. Second, a co-production model, through which researchers and users jointly produce climate services. The Tauranga City Council sea-level rise flood tool (see **Supplementary Figure 2**) was developed in this way. Researchers advised on appropriate storm-tide and SLR scenarios then used a dynamic model to predict flooding for several scenarios, which were mapped. Tauranga City Council then ground-truthed the maps and constructed an interactive web-based tool.

The games applications have created a key learning environment for decision makers when addressing coastal hazards, and the risks they bring for communities, sectors and government – greater understanding of the formal and informal rules that constrain or facilitate different types of adaptation; the role that values and aspirations play in decision making and how contested worldviews and competition for resources can be resolved in acceptable ways; how feedback from decision choices influence how paths can change as conditions change; how actions can be staged over time and funding prioritized; that risk cannot be totally removed and residual risk managed. The freedom to experiment and test different strategies within the rules and constraints of the game is perhaps one of the key strengths of the gaming approach. Players can fail and learn from that failure with no real consequences. However, if the rules are constructed to reflect a simplified version of reality, those lessons can be applied in the real world where choices <u>do</u> have implications.

TABLE 3 | Type of climate service with examples, purpose and lessons learned.

Type of climate service	Example	Purpose	Lesson learned
Long-term warning	Red-alert tide calendar	Annual to 3-monthly warning information of potential coastal flooding	Simple to grasp and use, visual aid, spawned citizen programme raising awareness
Long-term warning and raising awareness	Sea-level rise nomographs for frequency of high-tide exceedances	Long lead time warning information to create awareness of increasing coastal flooding	Increased confidence in the underpinning science, especially of the first tangible impact of SLR
Interactive spatial visual aids and maps ("sliders")	Coastal inundation for increasing SLR	Quick, visual, assessment of spatial risk exposure	Easy to use and appraise, informs spatial risk exposure. Applicable at many levels of public interest
Behavior change	Serious games	A decision learning tool that confronts participants with the implications of SLR and deepening uncertainty	Freedom to experiment and receive consequence feedback in a safe space. Raises need for adaptive decision making
Risk assessment and evaluation	RiskScape – a quantitative modular loss/damage system	Data on assets and people at risk and spatial analysis of consequences with SLR	Increased confidence by decision-makers in the quantum of risk in 0.1 m increments of SLR, informs adaptation priorities
Uncertainty and change assessment	Dynamic Adaptive Pathways Planning	An assessment and planning tool to address uncertainty and changing risk	Shifts thinking and planning from short-term protection strategies to longer-term on ongoing and changing risks

CONCLUSION

Making decisions in a dynamically changing environment poses significant challenges to coastal managers and decision makers. Assessment, planning, design of adaptations in coastal settings have been historically driven by impact/response models of decision making which have proven inadequate for a changing coastal setting where SLR is becoming the dominant driver of change (Le Cozannet et al., 2015).

The use of multiple reinforcing climate services that warn, monitor, review, and update, anticipate, build understanding and a capacity to act, operating within a fit for purpose institutional framework, can enable risks to be anticipated and deliver more robust decisions that are grounded in real-world practice. Synergies between these applications is giving a more nuanced understanding of what climate services are and how they can best be delivered. This has built trust in science where tools are clear, simple and address the users' problems (Schneider et al., 2020). The lessons learned in the application of the climate services discussed here have the prospect of shifting the perspectives about ongoing SLR (**Table 3**) and thus contributing further to the climate services field.

However, climate services by them selves are insufficient for addressing SLR. Increasingly, the role of the institutional context, multi-disciplinary practice and engagement with users and communities affected, are being recognized as essential for leveraging changed practice toward the use of adaptive processes supported by more relevant decision tools. For example, we have identified that the following institutional enablers have universal relevance.

- The critical importance of transparent and enabling governance arrangements (including Memoranda of Understanding with the parties) prior to starting strategy development.
- The value of a regional/local government partnership for coastal strategy development.
- The value of engaging collaboratively with communities by providing a "safe space" for deliberation, resulting in social learning about the practical issues around resilience efforts.
- The need for wider community engagement to encapsulate views on managing the risk and side-effects of options.
- The importance of considering a 100-year timeframe for vulnerability and risk assessments (using narratives and scenarios) and distilling the emergence of adaptation thresholds (i.e., when agreed objectives around levels of service and risk would no longer be met).
- Understanding how coastal hazard and risk/vulnerability assessments and the options/pathways assessment process using DAPP can be integrated and scaled, depending on the level of uncertainty and the planning situation.
- The value of an adaptive pathways approach for shifting thinking from short-term protection strategies to a longer-term focus on ongoing and changing risks.
- The risk of underestimating the time needed for developing the implementation plan, which includes regulatory planning, governance, funding, design and costings, triggers for monitoring and review.
- The importance of building capacity to employ the services, especially where resources are slim and there are few experts to work alongside decision makers.

Embedding new practice into "the way we do things around here," however, is often hampered by the slowness of policy decision making, which can swing wildly depending on political philosophy at national and local levels. This is a problem for consistency and alignment of values and outcomes which require bipartisan "agreement," adequate capacity building and the use of policy commitment devices (Boston and Lawrence, 2018). Climate services alone will not serve decisionmakers in the dynamic coastal space without the alignment of institutional frameworks across relevant domains of interest to increase the ability to implement adaptation options.

AUTHOR CONTRIBUTIONS

Micronesia. We thank Marjolijn Haasnoot, Deltares, Delft, Netherlands and University of Utrecht, Utrecht, Netherlands for reviewing an earlier draft of this manuscript and making useful suggestions. We thank the two reviewers for their feedback which improved the final manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.703902/full#supplementary-material

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