Designing decision-centric early warning systems for climate tipping points: the North Atlantic Subpolar Gyre as a test case

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Abstract

Early warning systems (EWS) for climate tipping point must support decisions to be useful. Using the potential near-term Subpolar Gyre tipping point as a test case, we develop a pre-elicitation framework linking Earth System science with decision-making. We show that no single EWS can meet diverse decision needs. Instead, the framework identifies shared decision architectures and information requirements, enabling scalable stakeholder co-design without bespoke systems for every user.

Early warning systems (EWS) for climate tipping points are increasingly promoted as essential tools for adaptation (e.g. 1,2), yet their development tends to prioritise the technical detection and prediction of physical precursors over the operational needs of the stakeholders they are intended to support (e.g. 3). The governance of risks and uncertainties associated with climate tipping points (4) presents a unique challenge because decision-makers often face the necessity of making consequential decisions before abrupt changes can be definitively detected, attributed, or forecast with sufficient confidence. Here, we focus on decisions that alter long-term investments, operational practices, or risk exposure in response to tipping point concerns, rather than broader climate risk planning. This is particularly critical for the North Atlantic Subpolar Gyre (SPG), where abrupt shifts in deep ocean winter convection and associated weather patterns could emerge as early as 2040s (5,6,7), posing systemic risks across the economy and society, including infrastructure, financial services, and food security planning (e.g. 4,8).

The SPG tipping point (TP) involves an abrupt weakening or collapse of deep winter convection, a key driver of North Atlantic Ocean circulation (e.g. 6). Unlike gradual warming, this shift may trigger rapid regional cooling and significant alterations to storm tracks and precipitation patterns, as well as potential destabilisation of the Atlantic Meridional Overturning Circulation (AMOC). For the North Atlantic region and surrounding countries, potential impacts include an increased frequency of extreme rainfall events, heightened coastal flood risks (e.g. 4), and fundamental disruptions to marine food webs, including changes in primary productivity and key zooplankton species such as Calanus spp. that support commercially important fish populations (e.g. 9).

While substantial investment is directed toward improving SPG detection and prediction (e.g. 10), improved detectability does not inherently guarantee operational usefulness for decision-making. Actionability depends on whether physical signals can be translated into decisions across diverse decision systems. Here, decision systems refer to the institutional, organisational, and operational contexts in which information is interpreted and acted upon, characterised by different objectives, constraints, timescales, flexibility, and action thresholds. We therefore develop a pre-elicitation framework in which actionable SPG EWS are represented as a four-layer architecture that includes: detection capability (L1), an impact translation layer (L2), a decision integration layer (L3), and an attribution layer (L4). These layers complement the operational components of conventional people-centred EWS architectures (monitoring, forecasting, communication and response; 3, 11) by defining additional decision-oriented capabilities required to translate warnings into action under deep uncertainty. The attribution layer (L4) represents a novel addition to existing EWS frameworks, determining whether observed socio-economic impacts are linked specifically to SPG dynamics or to concurrent drivers such as Arctic sea-ice decline or broader climate trends. The importance of this layer depends on the decision context: some sectors require attribution to justify costly preventive action, whereas others may act on observed impacts alone regardless of attribution.

This raises a practical question: how should EWS be designed when different organisations make fundamentally different types of decisions under different constraints, planning horizons, and capacities to manage uncertainty? For instance, an insurer with the ability to revise premiums annually may respond incrementally to emerging risks, whereas a coastal infrastructure planner making multi-decadal asset investments may require precautionary action long before a tipping point is robustly detected. We argue that the actionability of tipping point EWS information depends less on forecasting precision than on whether the warning is aligned with the decision-making context, especially the timescales over which decisions must be taken and implemented. We hypothesise that a small number of structural characteristics of decision-making systems determine how different organisations interpret and respond to early warning information. We developed and tested a structured framework to characterise how decisions are made in different sectors before formal stakeholder co-design begins. We define "decision architectures" in terms of their reversibility, update cadence and commitment duration (12, 13), we can determine how different sectors deal with tipping point uncertainty and optimise subsequent efforts on EWS co-design.

To test this hypothesis, we considered five stylised decision archetypes spanning a range of decision contexts, including operational decision-making (mortgage lending and flood insurance underwriting), long-term investment (coastal infrastructure), strategic planning (national food security), and resource management (marine ecosystems) (Table 1). These archetypes spanned a range of decision characteristics, including commitment timescales and reversibility. Participants, consisting of two separate cohorts of interdisciplinary scientists, were presented with a common "science kernel" representing three possible SPG trajectories: an early abrupt shift (2030s), a late abrupt shift (2050s), and a gradual change (no tipping) scenario. Participants were deliberately non-specialists in the sectors represented by the archetypes. This minimised the influence of sector-specific knowledge, ensuring that responses reflected differences in decision architecture rather than differences in prior expertise. For each archetype, participants were required to make recommendations about the strategy, identify relevant information triggers (ranging from climate-system metrics to operational losses), and prioritise research investments while ensuring that their decisions remain suitable for all three possible SPG trajectories. This two-stage process allowed for the iterative refinement of the framework, ensuring that decision characteristics like reversibility and update frequency were clearly distinguished.

Analysis of the responses (Table 2) reveals a consistent convergence in how structurally similar decision architectures operationalise identical SPG inputs across the three possible SPG trajectories considered (early abrupt shift, late abrupt shift, and gradual change). Systems characterised by high-frequency updates and high reversibility, such as insurance underwriting, tended to favour incremental adaptation strategies. Although such systems are sensitive to climate change, they so not necessarily depend on tipping-point-specific early warning; these systems can often adapt by responding to observed impacts and trends without requiring definitive attribution to SPG dynamics.

Participants reasoning within the infrastructure archetype, characterised by infrequent review cycles and long commitment duration, favoured the most precautionary adaptation strategy and relied most strongly on climate-system triggers (A1), reflecting the value of maximum warning lead time. However, participants still prioritised investment in decision integration (L3) over improvements in physical detection (L1). This preference may reflect a perception that the key challenge lies in making decisions under uncertainty rather than improving detection. Participants also identified an important question that is largely absent from current discussions of tipping-point early warning systems, but may be critical for long-term decision-making: whether an SPG tipping point introduces genuinely novel risks or simply accelerates risks already expected under gradual climate change.

Another significant finding is that decision integration (L3) and impact translation (L2) consistently emerge as higher research priorities, whereas improved detection (L1) and attribution (L4) are secondary. Within this elicitation exercise, this pattern suggests that participants perceived the main barriers to EWS actionability to lie less in physical detection and more in translating climate information into operationally relevant variables, such as frequency of climate extremes, frequency of flooding or marine productivity decline. This does not imply that improved monitoring, modelling, or attribution are unimportant, but rather highlights where participants identified the greatest decision-support needs.

A notable paradox emerged for irreversible decision archetypes, particularly coastal infrastructure, between research priorities and action triggers. Although relatively few participants prioritised further investment in attribution (L4), they frequently selected climate-system triggers (A1) to initiate action, even though such triggers inherently depend on robust attribution. This suggests that participants implicitly assumed that attribution would be sufficiently reliable when decisions became necessary, despite current scientific uncertainty. At present, robust attribution of regional impacts to a specific tipping mechanism such as SPG collapse remains highly uncertain. If operational decision-makers share the assumptions expressed by our participants, they may unknowingly rely on levels of attribution confidence that are not currently achievable. Future applications of the framework should therefore explicitly examine stakeholders' assumptions regarding attribution confidence, as these may substantially influence both research investment priorities and operational decision strategies.

Lastly, the results highlight another critical research gap: the relationship between the timing of the physical tipping-point processes and the timing of their societal consequences remains poorly quantified. These time lags are likely to be a key determinant of which EWS architecture is most appropriate for different decision architectures and stakeholders. Without a better understanding of how impacts may evolve through time following physical threshold crossings (in this case convection decline), it will remain difficult to establish effective early warning systems that provide actionable information.

In conclusion, our findings demonstrate that a single EWS is unlikely to meet the needs of all decision contexts. At the same time, our results suggest that many stakeholders share decision characteristics and therefore have broadly similar EWS requirements. These shared decision architectures can be identified before stakeholder engagement, shifting the challenge from designing bespoke EWSs for every stakeholder to designing a finite set of information architectures that address distinct classes of decision-making. Stakeholder co-design can then focus on refining these systems for specific operational contexts rather than defining them from scratch. This structured framework provides a roadmap for developing prototype EWS capabilities representing each decision architecture and enables evaluation of concrete information products (e.g. scenarios, risk indicators, hazard projections, and trigger metrics) rather than hypothetical possibilities. Our approach and identified decision architectures are transferable to other tipping elements with potentially near-term impacts such as Amazon dieback, provided the associated decision systems mirror contemporary structures of commitment and reversibility, a condition that may not hold for more distant risks such as tipping of the AMOC.

Method

The study consisted of five linked stages: (1) EWS framework development; (2) construction of decision archetypes; (3) scenario design; (4) iterative framework evaluation; (5) qualitative and quantitative analysis.

We define actionability as the extent to which an early warning system provides information that enables timely decisions before impacts occur within a given decision system. Whether an EWS is actionable depends not only on the quality of the warning, but also on the underlying decision architecture. In particular, it depends on structural characteristics of the decision-making system, including commitment duration (how long decisions commit resources), reversibility (how easily decisions can be revised), and update cadence (how frequently opportunities for action arise).

The objective of this study is not to infer how specific stakeholder groups would respond to SPG early warning information, but to develop and evaluate a pre-elicitation framework for identifying broad classes of decision architectures that may require different forms of early-warning information. The framework is intended to support subsequent stakeholder co-design rather than replace it.

1. EWS architecture

We developed a multi-layered architecture defining the essential functional components of an actionable SPG early warning system. The architecture was developed through synthesis of tipping-point EWS literature and decision-analysis concepts. The architecture provided the framework for the research-investment exercise, in which participants allocated investment across the four functional EWS layers (L1–L4):

L1 Detection Capability: Focuses on the physical monitoring and modelling of SPG-specific precursors, such as deep winter convection, ocean circulation, and phytoplankton levels.

L2 Impact Translation Layer: Translates physical climate signals into regional, regionally relevant hazards, including shifts in storm tracks, changes in precipitation and temperature extremes, and disruptions to ecosystem services.

L3 Decision Integration Layer: Defines the operational logic for acting under uncertainty, including how early warnings are translated into practical decisions, including when action should be taken and what that action should be.

L4 Attribution Layer: Determines whether observed environmental or socio-economic impacts can be attributed to SPG dynamics with sufficient confidence for the decision context or whether they may reflect concurrent drivers such as Arctic ice melt, multidecadal climate oscillations (e.g. NAO), or broader climate trends unrelated to tipping points.

While layers L1–L3 are commonly discussed, albeit primarily from a theoretical perspective, in the recent tipping-point EWS literature (e.g. 1; 14; 15; 16), the L4 Attribution Layer represents a novel element of EWS architecture. Although attribution of impacts to tipping point mechanisms has been widely investigated (e.g. 17; 18), explicit incorporation of attribution as a distinct functional layer within an EWS architecture has not, to the best of our knowledge, previously been proposed.

The L4 layer is particularly important where substantial investments are required to develop or maintain expensive monitoring capabilities (L1; e.g. 10) as well as for irreversible or high-cost adaptation decisions where precursor signals may precede societal impacts by a substantial time lag. Under these conditions, decision-makers may need to act on precursor signals before impacts become observable, making confidence in the causal link between precursor signals and subsequent impacts an important determinant of whether early action is justified.

2. Selection of decision archetypes

Five stylised decision archetypes (e.g. 19) were constructed to represent a range of decision contexts relevant to early warning signal use: flood insurance underwriting, mortgage lending, coastal infrastructure, food security, and fisheries management (Table 1). The stylised nature of the archetypes allows them to retain the key structural characteristics of real-world decision contexts while omitting organisation-specific details. Together they span public and private decision-making, financial and physical assets, and short- to long-term commitment horizons.

Each archetype was described using four structural characteristics that are likely to affect the use of early warning information: (i) decision commitment timescale, defined as the period over which a decision commits resources; (ii) decision flexibility or lock-in, defined as the extent to which the decision is reversible once taken; (iii) review or opportunity frequency, defined as how often the decision can be revisited; and (iv) exposure persistence, defined by the duration over which consequences remain if no action is taken (Table 1). The values shown represent stylised ranges intended to characterise the structural properties of each decision archetype rather than specific organisations or jurisdictions. They were developed through literature review and iterative interdisciplinary discussion to provide internally consistent comparisons across decision contexts.

The archetypes were intentionally stylised to isolate decision logic and support comparison across sectors. This simplification was deliberate, and the aim was to ensure plausibility and internal consistency rather than to reproduce any specific institution with high fidelity. Calibration was informed by iterative interdisciplinary discussion within the author team informed by published literature. This does not constitute a formal expert elicitation or validation exercise. As a result, the decision characteristics should be interpreted as a structured approximation of real-world decision architectures rather than a comprehensive or sector-exhaustive classification.

3. SPG scenario design

The SPG was selected as the focal tipping element because it potentially represents a near-term climate tipping risk (20) operating on timescales relevant to current adaptation and investment decisions. Unlike several other major tipping elements, including large ice-sheet instabilities and potential long-term AMOC collapse scenarios, the possibility of substantial SPG change within the coming decades places the risk within the planning horizon of many contemporary policy, infrastructure and financial decisions. The SPG therefore provides a useful test case for exploring how deep uncertainty associated with a potential tipping element can be operationalised within decision-making processes.

To represent uncertainty in the timing of a potential SPG convection collapse, we constructed three decision scenarios spanning a plausible range of outcomes identified in recent analyses of Earth System Models and tipping-point syntheses (e.g. 6; 7; 20; 21). These comprised i) an early abrupt shift in the 2030s, ii) a late abrupt shift in the 2050s, and iii) a gradual-change scenario in which no discrete tipping point occurs.

For the two abrupt-shift scenarios, the magnitude and nature of impacts were assumed to be identical, with only the timing of onset differing between scenarios. Whether all three scenarios would eventually converge towards a similar long-term climate state was assumed to lie beyond the decision horizon considered in this study and was therefore treated as out of scope. This simplification allowed participant responses to be attributed to differences in warning lead time rather than differences in impact severity.

The scenarios were designed to capture both abrupt and non-abrupt pathways consistent with current understanding of SPG variability and tipping risk. They should be interpreted as decision scenarios rather than climate projections, intended to support stress-testing of decision-making under deep uncertainty rather than to predict the timing or magnitude of future change. Accordingly, probabilities were intentionally not assigned, as the objective was to evaluate decision strategies under deep uncertainty rather than probabilistic forecasting.

4. Iterative framework evaluation

The framework was iteratively evaluated and refined through two structured interdisciplinary workshops. The workshops were designed to identify ambiguities, assess the clarity, internal consistency and practical usability of the framework across disciplines and collect independent participant judgements on decision strategies, research priorities, and action triggers. Participants comprised interdisciplinary researchers rather than operational decision-makers. The workshops were therefore designed as a methodological evaluation of the framework rather than an elicitation of stakeholder preferences. Participants were asked to reason within the constraints of each decision archetype, allowing assessment of whether the framework could generate systematically different responses across decision contexts.

Stage 1 (Pilot): Used to identify ambiguities in the archetype descriptions, decision characteristics and scoring system, and to assess overall comprehension of the framework. The key outcome was simplification of the scoring system, removal of redundant characteristics and introduction of human-centric storylines.

Stage 2 (Refinement): A second cohort evaluated the revised framework, after which the framework was frozen and used for the final independent ranking exercise involving all participants.

Scenario ranking (all participants): To ensure that all rankings were based on an identical framework, participants from both workshops independently completed the final ranking exercise after the framework had been finalised. For each decision archetype, participants selected (i) a preferred adaptation strategy following an early warning of an SPG tipping point (S1–S3; Appendix); (ii) the research investment they considered most valuable across the four EWS layers (L1–L4); and (iii) the trigger type that would lead them to revise the previously selected strategy following an early warning signal (A1–A4; Appendix). Participants were permitted to assign equal priority to more than one EWS layer. In these cases, votes were equally divided between the selected layers (e.g. 0.5/0.5 for two selections). Reported totals therefore represent weighted preferences and sum to the total number of participants.

Participants comprised 17 interdisciplinary researchers (8 in each cohort and the facilitator) spanning ocean and climate science (n = 7), interdisciplinary ocean–society research (n = 3), design and participatory research (n = 3), decision, policy and governance (n = 2), and economics and finance (n = 2). The workshops were intended to provide a broad interdisciplinary evaluation of the framework rather than a representative survey of any stakeholder group.

The objective was not statistical inference or consensus building but exploration of whether distinct decision architectures would produce distinguishable patterns of information demand under a common science scenario. Results should therefore be interpreted as evidence regarding the usability and discriminatory capacity of the framework rather than direct evidence of stakeholder behaviour.

5. Data Collection and Analysis

Qualitative data was gathered through structured group discussions, while quantitative preferences were captured via individual re-ranking using Google Forms to minimise peer influence during final ranking. Quantitative results were analysed descriptively using weighted preference scores. Given the exploratory nature of the study, the small sample size, and the absence of stakeholder representation, no statistical inference was attempted. Instead, the analysis focused on identifying recurring patterns and contrasts among decision archetypes that could inform future stakeholder engagement and framework refinement.

6. Limitations and intended use

This study represents an initial proof-of-concept evaluation of a pre-elicitation framework. Several limitations should be acknowledged. First, participants were researchers rather than operational stakeholders and therefore responses cannot be interpreted as representative of specific sectors. Second, the archetypes were intentionally simplified and do not capture the full diversity of real-world decision systems. Third, the sample size was designed to support framework testing rather than statistical analysis. Finally, the framework has not yet been validated through formal stakeholder co-design exercises. Future work should therefore focus on applying and refining the archetypes in collaboration with operational decision-makers, testing whether the decision architectures identified here are robust across sectors and governance contexts.

7. The use of AI

During the preparation of this manuscript, the authors used artificial intelligence (AI) tools for general editing, grammar and clarity improvements, and brainstorming the structural integration of the multi-layered framework. All core research findings, the development of the pre-elicitation framework, and the analysis of the expert ranking results remain the sole work of the authors and the interdisciplinary cohorts involved in the study.

Table 1. Characteristics of the five decision archetypes used in the framework. Values represent indicative ranges describing the typical decision architecture of each archetype rather than individual organisations. The characteristics are intended to support comparison of how different classes of decision systems may operationalise climate tipping point information under deep uncertainty.

Archetype	Decision commitment duration	Decision review frequency/opportunity for revision	Decision flexibility (lock-in)	Persistence of consequences if no action is taken	Decision consequence asymmetry
Insurance	1 yr (typical insurance policy term)	Months–1 year	High flexibility; pricing, coverage and portfolio exposure can be adjusted regularly	1 year	**Missed warnings generally outweigh false alarms.** False alarms may reduce competitiveness through precautionary pricing or restricted coverage; missed warnings can generate unexpectedly large claims and threaten insurer solvency.
Mortgage lending	20–35 years (typical mortgage term)	Days–months (new lending decisions)	Low flexibility once loans are issued	20–35 years	**Missed warnings generally outweigh false alarms.** False alarms may unnecessarily constrain lending and reduce profitability; missed warnings can lock lenders into decades of exposure to declining property values.
Infrastructure investment	20–100 years (ports ~20–40 y; flood defences ~50–100 y)	5–20 years (major planning and investment opportunities)	Very low flexibility; high capital lock-in	20–100 years	**Missed warnings strongly outweigh false alarms.** False alarms may lead to over-engineering; missed warnings can result in under-designed infrastructure, stranded assets, or costly retrofitting

National food security planning	5–30 years (adaptation strategies, agricultural transitions, trade arrangements)	1–5 years (policy and planning cycles)	Moderate flexibility; policies can be revised but implementation is slow	5–30 years	**Missed warnings strongly outweigh false alarms.** False alarms may lead to precautionary investments that prove unnecessary; missed warnings may result in widespread food insecurity, economic disruption and societal impacts that are difficult to reverse.
Fisheries/ecosystem management	1–10 years (annual quotas to multi-year management plans)	Months–1 year	High flexibility; quotas and management measures can be updated regularly	1–10 years	**False alarms and missed warnings are more evenly balanced.** False alarms may impose unnecessary economic costs to fishing communities; missed warnings may accelerate ecosystem degradation, stock declines and future economic losses.

Table 2. Preferred adaptation strategies and EWS information requirements across the five decision archetypes. Preferred strategies: S1 maintain current Approach, S2 moderate stress adjustment, S3 strong precautionary adjustment. EWS layer preference for research funding: L1 Detection Capability, L2 Impact Translation Layer, L3 Decision Integration Layer, L4 Attribution Layer. Dominant action trigger: A1 Climate-system action triggers, A2 Hazard-system triggers, A3 Operational-system triggers, A4 Policy/internal triggers (see Appendix for details). Fractions indicate the fraction of participant groups which voted for this EWS layer.

Archetype	Preferred Strategy	EWS layer preference	Dominant action trigger	Decision logic revealed
Insurance	S1 0.77 S2 0.23 S3 0	L1 0.06 L2 0.62 L3 0.32	A1 11.8 A2 35.3 A3 52.9	Flexible decision cycles and short term (~1yr) commitment duration favour incremental adaptation triggered by realised operational impacts rather than physical precursors.

		L4 0.00	A4 0	
Mortgage lending	S1 0.05 S2 0.82 S3 0.12	L1 0.12 L2 0.50 L3 0.35 L4 0.03	A1 0.24 A2 0.24 A3 0.24 A4 0.28	Long commitments but frequent lending opportunities favour precautionary adaptation informed by improved impact translation rather than direct climate-system indicators.
Infrastructure investment	S1 0 S2 0.29 S3 0.71	L1 0.18 L2 0.29 L3 0.44 L4 0.09	A1 0.35 A2 0.18 A3 0.18 A4 0.29	Irreversible, long-lived investments prioritise decision-support tools that enable precautionary planning under deep uncertainty but act on physical triggers which allow the longest warning.
National food security planning	S1 0 S2 0.59 S3 0.41	L1 0.08 L2 0.37 L3 0.53 L4 0.02	A1 0.24 A2 0.47 A3 0.12 A4 0.47	Moderate flexibility favours investment in decision integration and hazard-based triggers to support adaptive policy responses.
Fisheries/ecosystem management	S1 0.47 S2 0.47 S3 0.06	L1 0.15 L2 0.32 L3 0.24 L4 0.29	A1 0.29 A2 0.47 A3 0. A4 0.24	Regular management updates support adaptive responses while maintaining interest across multiple EWS information layers because both ecological and operational information are important. Attribution layer is important given multiple casual influences.

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Author contributions

E.P. conceived the study, developed the framework, and wrote the first draft of the manuscript. X.B., E.C., C.C., S.J., S.K., S.O., I.R.E., D.T. and A.H. participated in the first framework evaluation and contributed to its refinement. Z.J., A.L., A.M., J.M., J.N., J.P.R., CG and A.S.-F. participated in the second framework evaluation and contributed to its further refinement. All authors reviewed and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Data availability

All data generated or analysed during this study are included in this published article

References

References

1 Galmarini, S., ROMAN, C.R.M., Dentener, F., RUIZ, M.A., Alessi, L., ASIKAINEN, T., BATHIANY, S., CORBANE, C., DE, G.T., DENNIS, D.P. and DIMITRIVICS, A., 2025. Raising Awareness of Earth System Tipping Points: Implications for EU Governance. Workshop report, Publications Office of the European Union, Luxembourg, 2025, https://data.europa.eu/doi/10.2760/9047293, JRC141821.

2 Wood, R.A., Baker, J.A., Beaugrand, G. et al. Opportunities for Earth Observation to Inform Risk Management for Ocean Tipping Points. Surv Geophys 46, 443–502 (2025). https://doi.org/10.1007/s10712-024-09859-3

3. Basher, R., 2006. Global early warning systems for natural hazards: systematic and people-centred. Philosophical transactions of the royal society a: mathematical, physical and engineering sciences, 364(1845), pp.2167-2182. https://doi.org/10.1098/rsta.2006.1819

4 Lenton, T. M., Milkoreit, M., Willcock, S., Abrams, J. F., Armstrong McKay, D. I., Buxton, J. E., Donges, J. F., Loriani, S., Wunderling, N., Alkemade, F., Barrett, M., Constantino, S., Powell, T., Smith, S. R., Boulton, C. A., Pinho, P., Dijkstra, H. A. Pearce-Kelly, P., Roman- Cuesta, R. M., Dennis, D. (eds), 2025, The Global Tipping Points Report 2025. University of Exeter, Exeter, UK. ©The Global Tipping Points Report 2025, University of Exeter, UK.

5. Sgubin, G., Swingedouw, D., Drijfhout, S., Mary, Y., & Bennabi, A., 2017. Abrupt cooling over the North Atlantic in modern climate models. Nature Communications, 8(1), 14375. https://doi.org/10.1038/ncomms14375

6. Swingedouw, D., Bily, A., Esquerdo, C., Borchert, L.F., Sgubin, G., Mignot, J. and Menary, M., 2021. On the risk of abrupt changes in the North Atlantic subpolar gyre in CMIP6 models. Annals of the New York Academy of Sciences, 1504(1), pp.187-201.

7. Kelly, S., Popova, E., Yool, A., Jebri, F., Oliver, S. and Srokosz, M., 2025. Abrupt changes in the timing and magnitude of the north atlantic bloom over the 21st century. Journal of Geophysical Research: Oceans, 130(3), p.e2024JC022284. https://doi.org/10.1029/2024JC022284

8. Thompson, J.J., Wilby, R.L., Hillier, J.K. et al. Flood-affected homes in England lose value and are owned longer than those in unaffected areas. Commun Earth Environ 7, 530 (2026). https://doi.org/10.1038/s43247-026-03586-w

9. Pershing, A.J. and Stamieszkin, K., 2020. The North Atlantic ecosystem, from plankton to whales. Annual Review of Marine Science, 12(1), pp.339-359. https://doi.org/10.1146/annurev-marine-010419-010752

10. ARIA (2023) Forecasting Climate Tipping Points: Programme Thesis. Available at: https://aria.org.uk/media/wxrnowvq/aria-forecasting-climate-tipping-points-programme-thesis.pdf (Accessed: 13 July 2026).

11. United Nations International Strategy for Disaster Reduction (UNISDR), 2006. Developing early warning systems: A checklist. Third International Conference on Early Warning (EWC III), Bonn, Germany, 27–29 March. Geneva/Bonn: UNISDR Platform for the Promotion of Early Warning. https://www.preventionweb.net/files/608_10340.pdf?startDownload=true

12 Hallegatte, S., 2009. Strategies to adapt to an uncertain climate change. Global environmental change, 19(2), pp.240-247. https://doi.org/10.1016/j.gloenvcha.2008.12.003

13 Haasnoot, M., Kwakkel, J.H., Walker, W.E. and Ter Maat, J., 2013. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global environmental change, 23(2), pp.485-498. https://doi.org/10.1016/j.gloenvcha.2012.12.006

14 Lenton, T.M., 2011. Early warning of climate tipping points. Nature climate change, 1(4), pp.201-209. https://doi.org/10.1038/nclimate1143

15 Swingedouw, D., Ifejika Speranza, C., Bartsch, A., Durand, G., Jamet, C., Beaugrand, G. and Conversi, A., 2020. Early warning from space for a few key tipping points in physical, biological, and social-ecological systems. Surveys in geophysics, 41(6), pp.1237-1284.

16 Abrams, J.F., Lade, S.J., Donges, J., Ritchie, P., Ashwin, P., Constantino, S., Spaiser, V., Sillmann, J., Juhola, S., Aksenov, Y. and Laybourn, L., 2025. Introduction to Earth system tipping points risks. In Global tipping points report 2025 (pp. 97-106). University of Exeter.

17 Bastos, A., Sippel, S., Frank, D. et al. A joint framework for studying compound ecoclimatic events. Nat Rev Earth Environ 4, 333–350 (2023). https://doi.org/10.1038/s43017-023-00410-3

18 Bochow, N. and Boers, N., 2023. The South American monsoon approaches a critical transition in response to deforestation. Science Advances, 9(40), p.eadd9973.

19 Burger, K., 2025. Towards equitable, smart, and sustainable urban mobility: Governance archetypes and their relations. Transportation Research Part D: Transport and Environment, 145, p.104797. https://doi.org/10.1016/j.trd.2025.104797

20 McKay, D.I.A, Staal, A., Abrams, J.F., Winkelmann, R., Sakschewski, B., Loriani, S., Fetzer, I., Cornell, S.E., Rockström, J. and Lenton, T.M., 2022. Exceeding 1.5° C global warming could trigger multiple climate tipping points. 10.1126/science.abn7950

21 Oliver, S., Yool, A., de Mora, L., Kelly, S., Liddicoat, S. K., Loveridge, A., et al. (2026). The North Atlantic subpolar gyre and phytoplankton bloom under potential future climate scenarios. Journal of Geophysical Research: Oceans, 131, e2025JC023561. https://doi.org/10.1029/2025JC023561

Appendix 1. Decision archetype briefing documents used during the workshops

Participants evaluated five stylised decision archetypes representing distinct classes of decision-making under uncertainty. The five archetypes are:

- Decision Archetype 1: Flood insurance under SPG uncertainty
- Decision Archetype 2: Mortgage Risk Under SPG Uncertainty
- Decision Archetype 3: Coastal Infrastructure Investment Under SPG Uncertainty
- Decision Archetype 4: National Food Security Under SPG Uncertainty
- Decision Archetype 5: Marine Ecosystem Change and Fisheries Management

Each briefing document comprised: (i) a description of the decision context; (ii) the common SPG science kernel, consisting of three alternative future trajectories (early abrupt shift, late abrupt shift and gradual change); (iii) the principal decision trade-offs; (iv) a human-centred narrative illustrating the decision context; and (v) three ranking tasks covering adaptation strategy (S1–S3), EWS research priorities (L1–L4), and action triggers (A1–A4). The archetypes were intentionally simplified to isolate decision logic rather than reproduce the practices of any specific institution.

Decision Archetype 1: Flood insurance under SPG uncertainty

Your Role

You are advising a **UK insurance company** that provides flood insurance to households and businesses. The company must decide **how to adjust its risk models and pricing strategy** in response to potential SPG-driven changes.

You are **not expected to be insurance experts**. Your role is to use your understanding of **SPG impacts on precipitation, storms, and extremes**. Treat institutional mechanisms as simplified and focus on response logic.

SPG Scenarios (all three are possible, models disagree, early warning may not be possible)

- Early abrupt shift (~2030s)
- Late abrupt shift (~2050s)
- Gradual change (no abrupt shifts due to TP)

Current Situation

The insurer is **already accounting for climate change**:

Flood models already incorporate observed trends, catastrophe modelling and updated risk assessments

Premiums are adjusted based on updated risk maps

Reinsurance is used to manage extreme losses

However:
SPG change may:

Increase frequency and clustering of extreme rainfall events

Shift storm tracks (new regions exposed)

Produce non-linear changes not captured in current models

Early warning may be unavailable, unreliable, or non-actionable

The Insurer's Core Problem

Insurance operates on short decision cycles

• Premiums and underwriting criteria can be adjusted annually

• Exposure can often be reduced relatively quickly

Key Trade-offs

Acting early: loss of customers / competitiveness

Acting late: exposure to unexpected clusters of extreme losses before pricing can adjust

Illustrative human-centric storyline

The Narrative: A coastal homeowner receives a notice that their annual insurance premium has doubled. Although their property has never flooded, the insurer is pricing in a "precautionary margin" based on uncertain SPG-driven storm models

The Stake: This illustrates the tension between institutional solvency (acting late) and social exclusion (acting early), highlighting how short-term pricing cycles immediately impact household affordability

Your Task

Select:

One underwriting strategy (S1-S3)

One research investment area (L1–L4)

One action rule (A1-A4)

Underwriting Strategy (choose one)

Strategy option	Your decision

S1 - Maintain Current Models Continue updating models incrementally No explicit SPG adjustment	
S2 - SPG Stress Adjustment Add a precautionary margin to flood risk estimates Increase premiums moderately in exposed regions	
S3 - Strong Repricing Significantly increase premiums or withdraw coverage in high-risk areas	

EWS research investment strategy (choose one)

The insurance company has funding for one major research direction:

Research Investment	Your decision
L1 Detection capability: detect if/when change happens in SPG (observations and modelling)	
L2 Impact translation layer: what it means for UK risks (e.g. droughts, floods, storms, ecosystem disruptions)	
L3 Decision integration layer: how to act under uncertainty in this decision context (scenarios, thresholds)	
L4 Attribution layer: determine whether impacts are SPG-related or caused by other drivers (e.g. changes in the Arctic)	

Action rule (choose one)

What will trigger your action to modify an already-adopted strategy based on the new TP information:

Action Rule	Your decision
A1 Climate-system action triggers (SPG metrics, e.g. convection, SPG strength)	

A2 Hazard-system triggers (Floods, storms, droughts, ecosystem disruption)	
A3 Operational-system triggers (insurance losses, mortgage defaults, infrastructure failures, ecosystem collapse)	
A4 Policy/internal triggers (scheduled reviews, regulatory cycles)	

Decision Archetype 2: Mortgage Risk Under SPG Uncertainty

Your Role

You are advising a UK bank that provides home mortgages across England and Scotland. The bank must decide how to adapt its existing climate risk strategy in light of potential Subpolar Gyre (SPG) change. You are not expected to be finance experts. Your role is to use your understanding of SPG processes and impacts to guide robust decisions. Treat institutional mechanisms as simplified and focus on response logic.

SPG Scenarios (all three are possible, models disagree, early warning may not be possible)

Early abrupt shift (~2030s)

Late abrupt shift (~2050s)

Gradual change (no abrupt shifts due to TP)

Current Situation

The bank is already incorporating climate change into its decisions:

• Flood risk and other climate-related risks are considered within lending and stress-testing frameworks

• Climate scenarios are used to assess long-term portfolio exposure

• Regulatory requirements increasingly require climate-risk assessment

However:
SPG change introduces a different type of uncertainty:

• It may alter regional patterns of rainfall, flooding, storms and temperature

• It may produce abrupt changes not captured in current scenarios

• Early warning may be unavailable, unreliable, or non-actionable

• The implications for mortgage portfolios are indirect and uncertain

The Bank's Core Problem

The bank issues mortgages with repayment periods of up to 25 years, but:

- SPG-related impacts may emerge over similar timescales
- Decisions made today create long-term portfolio exposure
- Borrowers may face increasing financial stress in affected regions
- Property values may change if climate risks become more significant
- Mortgages can be repriced periodically, but existing exposure remains

Key Trade-offs

- SPG may amplify existing climate risks, but evidence is uncertain
- Early warning may not arrive in a usable form
- Acting early risks restricting lending unnecessarily
- Acting late risks accumulating long-term exposure to borrower default and declining collateral values

Illustrative human-centric storyline

The Narrative: A family is denied a 25-year mortgage on a home they can afford because the bank has flagged the region as "high risk" for the 2040s. The bank is acting on uncertain tipping point signals to avoid future exposure.

The Stake: This highlights the long-term commitment of lending and the risk of "restricting lending unnecessarily," potentially creating "stranded assets" decades before a tipping point is confirmed

Your Task

Select:

One lending strategy (S1-S3)

One research investment area (L1–L4)

One action rule (A1-A4)

Lending Strategy (choose one)

Strategy option	**Your decision**
S1 - Continue current climate strategy ("Nothing new here.") No specific adjustment for SPG Assume existing climate risk frameworks are sufficient	

S2 - SPG Adjustment layer Modify current approach to include additional precaution for SPG risk, e.g. slightly stricter lending criteria, higher capital buffers or adjusted pricing in vulnerable regions	
S3 - Strong Precautionary Shift Act as if SPG could significantly amplify risk Reduce long-term exposure more aggressively in potentially vulnerable regions	

EWS research investment strategy (choose one)

The bank has funding for one major research direction:

Research Investment	Your decision
L1 Detection capability: detect if/when change happens in SPG (observations and modelling)	
L2 Impact translation layer: what it means for UK risks (e.g. droughts, floods, storms, ecosystem disruptions)	
L3 Decision integration layer: how to act under uncertainty in this decision context (scenarios, thresholds)	
L4 Attribution layer: determine whether impacts are SPG-related or caused by other drivers (e.g. changes in the Arctic)	

Action rule (choose one)

What will trigger your action to modify an already-adopted strategy based on the new TP information:

Action Rule	Your decision
A1 Climate-system action triggers (SPG metrics, e.g. convection, SPH strength)	
A2 Hazard-system triggers (Floods, storms, droughts, ecosystem disruption)	

A3 Operational-system triggers (insurance losses, mortgage defaults, infrastructure failures, ecosystem collapse)	
A4 Policy/internal triggers (scheduled reviews, regulatory cycles)	

Decision Archetype 3: Coastal Infrastructure Investment Under SPG Uncertainty

Your Role

You are advising a **national planning body** responsible for **coastal infrastructure**.

You must decide **how to design and invest in infrastructure under SPG uncertainty**.

You are **not expected to be infrastructure experts**. Use your understanding of **SPG impacts on storms, flooding, and environmental variability**. Treat institutional mechanisms as simplified and focus on response logic.

SPG Scenarios (all three are possible, models disagree, early warning may not be possible)

Early abrupt shift (~2030s)

Late abrupt shift (~2050s)

Gradual change (no abrupt shifts due to TP)

Current Situation

Infrastructure planning already includes climate change considerations:

• Sea-level rise projections

• Changes in storm and flooding risk

• Engineering safety margins and design standards

• Long-term asset planning and investment appraisal

Major infrastructure decisions are often tied to planning, investment and regulatory review cycles

However:
SPG change may:

Alter **storm frequency and intensity patterns**

Increase **coastal flooding and infrastructure disruption**

Introduce **non-linear or abrupt shifts**

Early warning may be unavailable, unreliable, or non-actionable

The Core Problem

Infrastructure:

• Takes 5–15 years to plan and build

• Often remains in operation for several decades

• Decisions are infrequent and difficult to reverse

• Future climate risks must be considered before impacts are fully observable

Key question:

Should infrastructure be designed differently now to avoid future lock-in, even if SPG impacts remain uncertain?

Key Trade-offs

• Early investment: higher costs and potential overdesign
• Delayed action: long-term lock-in of infrastructure that may be difficult or expensive to upgrade later

Illustrative human-centric storyline

The Narrative: A port authority must decide whether to spend millions to raise sea walls now or wait for more certain data. If they wait and the SPG collapses, the town's primary economic hub will be permanently lost to storm surges by 2050.

The Stake: This demonstrates the problem of **long-term lock-in** and the high cost of reversing infrastructure decisions, pitting **upfront efficiency** against **long-term public safety**

Your Task

Select:

One infrastructure investment strategy (S1-S3)

One research investment area (L1–L4)

One action rule (A1-A4)

Infrastructure investment strategy (choose one)

Investment Strategy	Your decision
S1 -Current design standards • Continue with existing climate-aware design standards and planning assumptions	
S2 -Moderate upgrade Increase resilience margins (e.g. flood protection, storm tolerance)	

S3 -Strong Precautionary Design • Design for severe SPG-driven amplification of future risks • Accept substantially higher upfront costs to increase long-term resilience	

EWS research investment strategy (choose one)

The planning body has funding for one major research direction:

Research Investment	Your decision
L1 Detection capability: detect if/when change happens in SPG (observations and modelling)	
L2 Impact translation layer: what it means for UK risks (e.g. droughts, floods, storms, ecosystem disruptions)	
L3 Decision integration layer: how to act under uncertainty in this decision context (scenarios, thresholds)	
L4 Attribution layer: determine whether impacts are SPG-related or caused by other drivers (e.g. changes in the Arctic)	

Action rule (choose one)

What will trigger your action to modify an already-adopted strategy based on the new TP information:

Action Rule	Your decision
A1 Climate-system action triggers (SPG metrics, e.g. convection, SPH strength)	
A2 Hazard-system triggers (Floods, storms, droughts, ecosystem disruption)	
A3 Operational-system triggers (insurance losses, mortgage defaults, infrastructure failures, ecosystem collapse)	
A4 Policy/internal triggers (scheduled reviews, regulatory cycles)	

Decision Archetype 4: National Food Security Under SPG Uncertainty

Your Role: You are advising a UK government team responsible for national food security (domestic production, imports, and supply resilience). The team must decide how to adjust strategy in response to potential SPG-driven changes. Major food-security decisions are often made through periodic policy and risk-assessment cycles rather than in response to individual climate signals.

You are not expected to be agriculture experts. Your role is to use your understanding of SPG impacts on weather variability, extremes, and supply systems. Treat institutional mechanisms as simplified and focus on response logic.

SPG Scenarios (all three are possible, models disagree, early warning may not be possible)

Early abrupt shift (~2030s)

Late abrupt shift (~2050s)

Gradual change (no abrupt shifts due to TP)

Current Situation

National food security planning is already accounting for climate change:

• Crop yield projections include warming and rainfall changes

• Food security assessments consider both domestic production and imports

• Supply chains are diversified across regions and trading partners

• Contingency planning exists for shocks (e.g. poor harvests, price spikes and supply disruptions)

However:

SPG change may:

Increase variability and clustering of poor harvest years

Affect both UK production and key import regions

Produce non-linear changes not captured in current planning

Early warning may be unavailable, unreliable, or non-actionable

The Core Problem

Food security depends on interconnected production, trade and supply systems, but:

• SPG-related impacts may emerge gradually or abruptly

• Risks may affect multiple regions simultaneously

• Decisions about resilience and contingency planning often operate on multi-year timescales

• Early warning may be unavailable, unreliable, or non-actionable

Key Trade-offs

• Acting early: additional costs, inefficiencies and potentially unnecessary resilience measures

• Acting late: increased vulnerability to supply disruptions, price spikes and food-system shocks

Illustrative human-centric storyline

The Narrative: A government planner faces empty supermarket shelves and skyrocketing food prices due to a cluster of poor harvests. They must defend why they did not invest in expensive strategic reserves years earlier when the first SPG signals emerged.

The Stake: This illustrates systemic vulnerability and the political difficulty of justifying costly "inefficiencies" (redundancy) before a crisis materialises

Your Task

Select:

One food security strategy (S1-S3)

One research investment area (L1–L4)

One action rule (A1-A4)

1. Food Security Strategy (choose one)

Strategy option	Your decision
S1 – Maintain Current Approach Continue existing climate-adjusted planning No explicit SPG adjustment	
S2 – Incremental Adjustment Increase resilience modestly (e.g. diversification, contingency planning, strategic buffers) Include SPG as an additional uncertainty	
S3 – Strong Precautionary Shift Invest significantly in: domestic resilience (production, storage and supply chains)	

strategic reserves and contingency capacity diversification of import sources Assume potential for clustered supply disruptions affecting multiple regions	

EWS research investment strategy (choose one)

The government department has funding for one major research direction:

Research Investment	Your decision
L1 Detection capability: detect if/when change happens in SPG (observations and modelling)	
L2 Impact translation layer: what it means for UK risks (e.g. droughts, floods, storms, ecosystem disruptions)	
L3 Decision integration layer: how to act under uncertainty in this decision context (scenarios, thresholds)	
L4 Attribution layer: determine whether impacts are SPG-related or caused by other drivers (e.g. changes in the Arctic)	

Action rule (choose one)

What will trigger your action to modify an already-adopted strategy based on the new TP information:

Action Rule	Your decision
A1 Climate-system action triggers (SPG metrics, e.g. convection, SPH strength)	
A2 Hazard-system triggers (Floods, storms, droughts, ecosystem disruption)	
A3 Operational-system triggers (insurance losses, mortgage defaults, infrastructure failures, ecosystem collapse)	
A4 Policy/internal triggers (scheduled reviews, regulatory cycles)	

Decision Archetype 5: Marine Ecosystem Change and Fisheries Management

Your Role

You are advising a **marine management authority** responsible for fisheries in the North Atlantic. Your task is to decide **how management frameworks should respond to the possibility of additional SPG-driven shifts.**

You are **not expected to be fisheries experts**. Use your understanding of **SPG dynamics and ecosystem processes**. Treat institutional mechanisms as simplified and focus on response logic.

SPG Scenarios (all three are possible, models disagree, early warning may not be possible)

Early abrupt shift (~2030s)

Late abrupt shift (~2050s)

Gradual change (no abrupt shifts due to TP)

Current Situation

Marine ecosystems are **already changing under climate change**:

Changes in species distributions, productivity and phenology

Increasing variability in stock assessments

Fisheries management is adapting through:

• Stock-based quotas and harvest control rules

• Periodic stock assessments and management reviews

• Increasing interest in ecosystem-based approaches

• Management frameworks that already respond to observed ecosystem change

However SPG change may:

Alter large-scale circulation and ecosystem productivity

Affect key species and food-web structure (e.g. Calanus spp.)

Modify the distribution and productivity of commercially important stocks

Introduce **non-linear or abrupt ecosystem reorganisation**

Early warning may be unavailable, unreliable, or non-actionable

Decisions are updated regularly but changes are hard to attribute and may be systemic

The additional challenge: Attribution limits

• Ecosystem changes are already occurring due to climate change, fishing pressure and natural variability

• Similar ecological changes may arise from multiple causes

• Attribution to SPG may be uncertain and may lag decision needs

• Managers may question whether SPG-specific information changes decisions that would be taken anyway

Existing management systems can already respond to ecosystem change, raising the question of whether SPG-specific information would alter decisions in practice.

The Core Problem

Fisheries management must:

Set quotas and regulations **regularly (annual/multi-year)**

Maintain ecological sustainability AND economic viability

Should management frameworks change in response to a *possible but unprovable* SPG influence on already shifting ecosystems?

Key Trade-offs

• Acting on SPG risk - may misattribute ecosystem change and introduce unnecessary restrictions

• Ignoring SPG - may miss an important driver of ecosystem reorganisation

• Waiting for attribution - may delay action until ecological changes are already underway

Illustrative human-centric storyline

The Narrative: A fishing fleet captain is ordered to reduce his catch by 30% due to a "plausible but unprovable" SPG-driven decline in productivity. He argues the change is just natural variability and that the restriction is an "unnecessary" blow to his livelihood.

The Stake: This highlights the **attribution layer (R4)** and the **institutional legitimacy** required to impose restrictions when the causal driver remains uncertain

Your Task: Select:

One ecosystem management strategy (S1-S3)

One research investment area (L1–L4)

One action rule (A1-A4)

1. Ecosystem management strategy (choose one)

Strategy option	Your decision
S1 - Maintain Current Adaptive Management Continue incremental adjustments based on observed stock changes No explicit SPG consideration	

S2 - SPG-Informed Adjustment Incorporate SPG as an additional ecosystem risk factor Apply greater precaution where SPG-related ecosystem sensitivity is considered plausible	
S3 - Strong Precautionary Management Reduce quotas for vulnerable / uncertain stocks Apply precaution broadly in anticipation of possible ecosystem reorganisation	

EWS research investment strategy (choose one)

The management authority has funding for one major research direction:

Research Investment	Your decision
L1 Detection capability: detect if/when change happens in SPG (observations and modelling)	
L2 Impact translation layer: what it means for UK risks (e.g. droughts, floods, storms, ecosystem disruptions)	
L3 Decision integration layer: how to act under uncertainty in this decision context (scenarios, thresholds)	
L4 Attribution layer: determine whether impacts are SPG-related or caused by other drivers (e.g. changes in the Arctic)	

Action rule (choose one)

What will trigger your action to modify an already-adopted strategy based on the new TP information:

Action Rule	Your decision
A1 Climate-system action triggers (SPG metrics, e.g. convection, SPH strength)	
A2 Hazard-system triggers (Floods, storms, droughts, ecosystem disruption)	

A3 Operational-system triggers (insurance losses, mortgage defaults, infrastructure failures, ecosystem collapse)	
A4 Policy/internal triggers (scheduled reviews, regulatory cycles)	