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Assessing and reducing vulnerability to climate change: Moving from theory to practical decision-support

Johanna E. Johnson[a,b,*], David J. Welch[c,d], Jeffrey A. Maynard[e,f], Johann D. Bell[g,1], Gretta Pecl[h,i], Julie Robins[j], Thor Saunders[k]

[a] C_2O coasts climate oceans, Cairns 4870, Australia
[b] College of Marine & Environmental Sciences, James Cook University, Cairns 4870, Australia
[c] C_2O Fisheries, Cairns 4870, Australia
[d] Centre for Sustainable Tropical Fisheries and Aquaculture, College of Marine and Environmental Sciences, James Cook University, Townsville 4811, Australia
[e] SymbioSeas and Marine Applied Research Center, Wilmington, NC 28411, USA
[f] Laboratoire d'ExcellenceCORAIL USR 3278 CNRS—EPHE, CRIOBE, Papetoai, Moorea, Polynésie française
[g] Secretariat of the Pacific Community, Noumea, New Caledonia
[h] Institute for Marine and Antarctic Studies, Fisheries & Aquaculture Centre, University of Tasmania, Hobart 7001, Australia
[i] Centre for Marine Socioecology, University of Tasmania, Hobart, Tasmania 7001, Australia
[j] Agri-Science Queensland, Department of Agriculture and Fisheries, Brisbane, Australia
[k] Northern Territory Department of Primary Industry and Fisheries, Darwin 0800, Australia

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A B S T R A C T

As climate change continues to impact socio-ecological systems, tools that assist conservation managers to understand vulnerability and target adaptations are essential. Quantitative assessments of vulnerability are rare because available frameworks are complex and lack guidance for dealing with data limitations and integrating across scales and disciplines. This paper describes a semi-quantitative method for assessing vulnerability to climate change that integrates socio-ecological factors to address management objectives and support decision-making. The method applies a framework first adopted by the Intergovernmental Panel on Climate Change and uses a structured 10-step process. The scores for each framework element are normalized and multiplied to produce a vulnerability score and then the assessed components are ranked from high to low vulnerability. Sensitivity analyses determine which indicators most influence the analysis and the resultant decision-making process so data quality for these indicators can be reviewed to increase robustness. Prioritisation of components for conservation considers other economic, social and cultural values with vulnerability rankings to target actions that reduce vulnerability to climate change by decreasing exposure or sensitivity and/or increasing adaptive capacity. This framework provides practical decision-support and has been applied to marine ecosystems and fisheries, with two case applications provided as examples: (1) food security in Pacific Island nations under climate-driven fish declines, and (2) fisheries in the Gulf of Carpentaria, northern Australia. The step-wise process outlined here is broadly applicable and can be undertaken with minimal resources using existing data, thereby having great potential to inform adaptive natural resource management in diverse locations.

1. Introduction

Understanding vulnerability to climate change provides insight into which parts of social-ecological systems are most likely to change, what is driving this potential change, and how conservation and management actions can minimise impacts and maximise resilience. Assessing the vulnerability of species, ecosystems and resource-dependent industries to climate change is a critical step to identify effective adaptations and prioritise management that enhances resilience. Vulnerability is the degree to which a system or species is susceptible to, or unable to cope with, the adverse effects of climate change [1], and depends on exposure (extrinsic factors), sensitivity and adaptive

* Corresponding author at: C_2O coasts climate oceans, PO Box 3041, Cairns 4870, Australia.
E-mail addresses: johanna.johnson@jcu.edu.au (J.E. Johnson), d.welch@c2o.net.au (D.J. Welch), maynardmarine@gmail.com (J.A. Maynard), b.johann9@gmail.com (J.D. Bell), Gretta.Pecl@utas.edu.au (G. Pecl), Julie.Robins@daf.qld.gov.au (J. Robins), thor.saunders@nt.gov.au (T. Saunders).
[1] Present address: Australian National Centre for Ocean Resources and Security, University of Wollongong, NSW 2522, Australia.

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capacity (intrinsic factors). The Intergovernmental Panel on Climate Change (IPCC) has provided an approach to understanding vulnerability and its elements that has become a universally recognised vulnerability assessment framework [2]. In the IPCC framework, exposure and sensitivity determine potential impacts, which are tempered by adaptive capacity to yield vulnerability to climate change.

In this framework, exposure is defined as the degree to which the component assessed (e.g. species, ecosystem or resource-dependent industry or community) is likely to experience climate change at the local scale, given their preferred habitats, ranges, behaviour and mobility. Sensitivity is the degree to which a component can be directly altered by a change in climate or indirectly altered, for example, by a change in a species' habitat. Adaptive capacity is the potential to reduce exposure or adjust sensitivity so as to maximise fitness and moderate or cope with the detrimental effects of climate change [1]. These terms are commonly used when assessing vulnerability and are consistent with existing approaches [see 3,4,5]. Assessing the vulnerability of complex socio-ecological systems (SES) to climate change can identify effective adaptation options and help construct targets for resilience-based management [6].

There has been an evolution in thinking on climate change vulnerability over the last 15 years [7–9] and a range of approaches to assess vulnerability have been proposed and applied [e.g. 4,10,11,12]. Central to all existing approaches is understanding and accounting for the complexity and uncertainty associated with: climate change and other global stressors, the integration of social and ecological data, and SES thresholds of change [13]. These are multi-faceted challenges typically addressed with resource-intensive methods that require significant data and/or expertise, e.g. multi-dimensional models [14], fuzzy cognitive mapping [15], paleo-ecological reconstructions or scenarios as proxies [16]. Management uptake of these approaches has been limited, creating a niche for a relatively simple, robust semi-quantitative approach to assess vulnerability to climate change.

In response, criteria-based approaches have emerged that use indices for social and ecological factors or 'indicators' and then integrate scores or classifications for indicators to produce a relative assessment of either vulnerability or resilience [17–21]. In addition, for many developing countries, although national assessments of vulnerability to climate change are available they cannot be easily downscaled and localized assessments that provide species-, community- or location-specific information are required.

2. Method

The framework described here for semi-quantitatively assessing vulnerability to climate change builds on this recent thinking to provide a framework for local assessments. The framework has evolved through applications by the author team to ecosystems [22–24], national industries and economies [25,26], fisheries [17,27,28], resource-dependent communities [20,26,29], and aquaculture [30]. This evolution has refined techniques for identifying and selecting indicators and for quantifying ecological responses. The result is a broadly applicable assessment framework and step-wise process, and a practitioners guide is provided in the Supplementary Material. The process uses available data and expert judgment to generate results on relative vulnerability for practical decision-support targeting management and conservation.

2.1. Semi-quantitative assessment method

The semi-quantitative assessment (SQA) method involves a customisable 10-step process that directs the assessment focus and application of results, particularly for targeting management (Fig. 1). Glick et al. [31] outlined the key steps for assessing vulnerability to climate change, with the vulnerability assessment results informing broader adaptation planning. Building on this concept, the SQA method presented here includes clear steps to assess climate change vulnerability (steps 2–8) as well as applying results to inform adaptation (steps 9 and 10). All 10 steps may not be applicable in all circumstances, and selecting which steps to complete is part of customising the process to the study context. In particular, 'review and reassess' (step 8) may not be required depending on the results of the sensitivity analysis. Similarly, 'prioritisation' (step 9) may be skipped if the selection of components (in step 2) already considered values and importance. The SQA method is designed for application by decision-makers seeking transparent support for managing natural resources, conservation areas, community-based actions and climate change impacts (see practitioners guide in the Supplementary Material). Including participation by local experts, stakeholders and communities throughout the process ensures the results are robust and maximises uptake, delivering direct translation to management actions [32,33].

The described framework has already been applied by tailoring the 10 steps to assess the vulnerability of ecosystems and communities in tropical SES's. Two of these applications are summarised in detail as case examples of applying the 10 steps: (1) Pacific Island food security from fisheries [17,25]; and (2) Gulf of Carpentaria fisheries [28], in Section 3 and a third application – Torres Strait fisheries [20] – is used to demonstrate the method in each step of the SQA method and in Fig. 1.

2.1.1. Step 1: set management objectives

This step involves managers and stakeholders determining the core objectives and scope of the assessment and how the results will inform decision-making. The objectives will determine the management needs, scale (spatial and temporal) of the assessment, components to be assessed, and ultimately the focus of any identified management actions. Determining the scale of the assessment includes which climate projections and impacts are most relevant for the management objectives, in terms of future timeframes and emissions scenarios. For example, the objectives of the Pacific Island food security SQA were to identify: (1) which nations were most vulnerable to climate-driven declines in fish supply by 2035 under a high emissions scenario, and, (2) which fisheries adaptations can support filling the gap between demand and supply [17,25].

2.1.2. Step 2: set vulnerability assessment focus

This step involves selecting the SES components to assess (e.g. species, habitats, resource-dependent industries or communities) and the type of sensitivity analyses to conduct in partnership with local experts and stakeholders. This step also requires identifying situation-appropriate indicators and criteria. The case applications outlined in this paper used a workshop brainstorming session to choose a representative suite of components that are relevant to the management objectives. The selection can be based on specific criteria, for example: (1) conservation, social, economic and/or cultural importance; (2) known or expected sensitivity to climate change; and/or (3) data availability [28]. A review process with a wide group of stakeholders is used to validate the selected list of components to assess. Stakeholder engagement should be as inclusive of different stakeholder types as possible but guided by the stakeholders likely to be most affected by climate change, similar to that described by Heenan et al. [33].

2.1.3. Step 3: identify and select indicators

The SQA uses known biology, ecology and responses to climate variation to develop a series of indicators for: (i) exposure, (ii) sensitivity and (iii) adaptive capacity. Indicators for exposure are based on climate projections. Sensitivity indicators are based on known tolerances or responses to environmental variables [e.g. 27]. Indicators for adaptive capacity are based on research that identifies which characteristics (or traits) of species/systems support recovery and ultimately confer resilience [e.g. 34–38]. The exposure, sensitivity