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Climate change, multiple stressors and human vulnerability : a systematic review

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1 **Climate change, multiple stressors and human vulnerability – a systematic**
2 **review**

3

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15

16 **Abstract**

17 We systematically reviewed current climate change literature in order to examine how multiple
18 processes that affect human vulnerability have been studied. Of the 125 reviewed articles, 79 %
19 were published after 2009. There are numerous concepts that point out to stressors other than
20 climate change that were used in reviewed studies. These different concepts were used
21 interchangeably and they illustrate processes that act on different scales. Most widely used concepts
22 included non-climatic (40% of the articles), multiple stressors (38%) and other factors (37%). About
23 75% of the studies either acknowledged or carefully analyzed the social and environmental context
24 in which vulnerability is experienced. One third of the studies recognized climate change related
25 stressors as the most important, one third argued that stressors other than climate are more
26 important and the rest of the studies did not analyze the relative importance of the different
27 processes. Interactions between different stressors were mentioned in 76% and analyzed explicitly
28 in 28% of the articles. Our review shows that there are studies that analyze the social context of
29 vulnerability within climate change related literature and this literature is rapidly expanding.
30 Reviewed studies point out that there are multiple interacting stressors, whose interlinkages need to
31 be carefully analyzed and targeted by policies, which integrate adaptation to climate change and
32 other stressors. In conclusion, we suggest that future studies should include analytical frameworks
33 that reflect dissimilarities between different types of stressors, methodological triangulation to
34 identify key stressors and analysis of interactions between multiple stressors across different scales.

35

36 Keywords: adaptation; non-climatic; driver; exposure; pressure; risk

37

38

39

1 Introduction

Within the literature on climate change and human vulnerability (*i.e.* vulnerability of individuals, communities, societies and human systems), climate change has been conventionally seen as the main driver of vulnerability. This is evident for instance in the definition suggested by the Intergovernmental Panel on Climate Change. The widely used IPCC definition of the Fourth Assessment Report states that “[*V*]ulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.” (IPCC 2007).

This definition has become the most widely used in the climate change vulnerability literature (Bassett and Fogelman 2013; Füssel and Klein 2006) thus having a major influence on research. Furthermore, it has been argued that this particular interpretation of vulnerability affects the practical policies considering adaptation to climate change and the reduction of vulnerability (O'Brien et al. 2007).

In addition to the IPCC, there are wide array of different definitions of vulnerability and different frameworks through which the concept has been operationalized in research (Adger 2006; Berry et al. 2006; Birkmann 2006; Eakin and Luers 2006; Füssel 2007; Füssel and Klein 2006; Giupponi and Biscaro 2015; Hinkel 2011; McLaughlin and Dietz 2008; Ribot 2014; Turner et al. 2003). Furthermore, although IPCC definitions did not change considerably between the First and the Fourth assessment report (Bassett and Fogelman 2013), a major change can be seen from the Fourth to the most recent Fifth report. In the 5th assessment report (AR5) of the IPCC working group 2 (WG2), the central focus is on climate-related risks instead of vulnerability.

66 In the IPCC (2014) climate risk framework, risk is the result of interaction of hazard, exposure and
67 vulnerability. Hazard refers to a physical event, trend or their impacts that have an effect on human
68 or natural systems; exposure means the presence of people or other unit of interest in settings,
69 where there can be adverse effects; while vulnerability is defined as follows: *"The propensity or*
70 *predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and*
71 *elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt."*
72 (IPCC 2014).

73

74 This latest IPCC definition is hence more general as recommended before by various authors
75 (Hinkel 2011; Wolf et al. 2013). Climate change or other biophysical concepts are no longer
76 mentioned in the definition, although they are still embedded in the new hazard concept as part of
77 climate risk. In this climate risk framework, exposure and vulnerability can also increase risks
78 alongside the physical hazards (Mechler et al. 2014). This new conceptual vagueness does not,
79 however, necessarily mean that social factors, which are important issues in shaping the
80 vulnerability context (O'Brien et al. 2007; Ribot 2014), have a more central role in the IPCC climate
81 risk framework and on research and policies that utilize the framework.

82

83 These definitions and frameworks have been elaborated within different orientations, which have
84 divergent views on what causes vulnerability (Adger 2006; Birkmann 2006; Eakin and Luers 2006;
85 Füssel and Klein 2006; Giupponi and Biscaro 2015; McLaughlin and Dietz 2008; Ribot 2014).

86 Some political-ecological –oriented researchers have, for example, criticized that the earlier hazard
87 literature did not carefully consider the social aspects of vulnerability (Bassett and Fogelman 2013;
88 Ribot 2014); and the same critique has been directed to the IPCC vulnerability and adaptation
89 framework (Bassett and Fogelman 2013).

90

91 Within climate change literature, this duality of approaches has been called end-point and starting-

92 point (Kelly and Adger 2000), top-down and bottom-up (Dessai and Hulme 2004) or outcome and
93 contextual (O'Brien et al. 2007). The end-point approach evident in the IPCC Fourth Assessment
94 Report (IPCC 2007) considers vulnerability as an outcome of climate change, whereas the second
95 approach regards vulnerability as part of multidimensional, context-specific climate-society
96 interactions. It has been argued that the wider socio-cultural, political-economic and environmental
97 contexts of vulnerability are important both analytically (O'Brien et al. 2007) and also in practical
98 adaptation policy (Eriksen et al. 2011).

99

100 Approaching vulnerability as contextual directs attention to the cascading effects of different
101 political-economic, and socio-ecological processes that make people differentially vulnerable to
102 changes in their environment. It consequently has been argued that climate change is but one of
103 'multiple stressors' (Adger 2006; O'Brien et al. 2004; Turner et al. 2003) that cause vulnerability. In
104 addition to 'multiple stressors', other concepts have emerged, including 'non-climatic factors'
105 (Füssel and Klein 2006), 'double exposure' (O'Brien and Leichenko 2000), 'multiple exposures'
106 (Belliveau et al. 2006; Bennett et al. 2015a) and 'other stressors' (Tschakert 2007).

107

108 Some researchers have argued that especially within hazards research 'multiple stressors' have been
109 studied for decades (Kelman et al. 2015); whereas others argue that 'multiple stressors' is a
110 relatively new issue (Bennett et al. 2015a). Although 'multiple stressors' were mentioned already in
111 the first IPCC reports, in fact, the focus has often concentrated on single stressors using *ceteris*
112 *paribus* assumption (Hashimoto et al. 1990).

113

114 This discussion illustrates that the idea of 'multiple stressors' and 'non-climatic factors' has been
115 incorporated as part of the climate change and vulnerability discussion. Some authors have even
116 tried to identify all different driving factors of vulnerability. Zou and Wei (2010) classified in their
117 review 361 different driving factors of social vulnerability in coastal Southeast Asia. In another

118 review, Bennett et al. (2015a) gave examples of different stressors/exposures that are evident in
119 coastal areas constructing a conceptual framework on how ‘multiple exposures’ can be analyzed.

120

121 There are many analyses of different orientations and definitions of vulnerability research (Adger
122 2006; Birkmann 2006; Eakin and Luers 2006; Füssel and Klein 2006; McLaughlin and Dietz 2008;
123 Ribot 2014), approaches with typologies of ‘multiple stressors’ (Bennett et al. 2015a; Zou and Wei
124 2010) and some recent systematic reviews or bibliometric analyses of vulnerability (Delaney et al.
125 2014; Giupponi and Biscaro 2015; McDowell et al. 2016; Tucker et al. 2014; Wang et al. 2014).

126 However, none have looked systematically at how ‘multiple stressors’ have been conceptualized in
127 the climate change and human vulnerability literature.

128

129 We synthesize the current knowledge on ‘multiple stressors’ and show that the current literature
130 about ‘multiple stressors’ is relatively new field. Furthermore, we contribute to the conceptual and
131 analytical clarity of this of study and hence help in bridging various approaches researching
132 vulnerability. Our review has important policy implications because the ‘multiple stressors’
133 literature highlights the various processes which, in addition to climate change, increase
134 vulnerability and which should be accounted for in climate change adaptation policies.

135

136 **2 Methods**

137

138 Systematic reviews are especially useful in synthesizing current knowledge and they are transparent
139 in their methods (Berrang-Ford et al. 2015; Lorenz et al. 2014). We systematically reviewed
140 selected climate change literature following the methodology suggested by Berrang-Ford et al.
141 (2015). They propose three components for the systematic review of climate change adaptation
142 research: (1) explicit objectives of the review and clear description of the conceptual approach used,
143 (2) justification of the literature source, detailed description of the search process, description of the

144 inclusion/exclusion criteria and documentation of the literature as well as (3) description of the
145 methods and critical appraisal of information quality.

146

147 Our overall objective was to systematically analyze different concepts that denote stressors other
148 than climate and that are used in the literature about climate change and human vulnerability. More
149 specifically, we examined (1) how widely investigated and how novel the literature about ‘multiple
150 stressors’, ‘non-climatic factors’ and other similar concepts is within the literature about human
151 dimensions of climate change, (2) how these concepts have been used and what differences there
152 are between concepts and (3) what is the relative importance of different stressors.

153

154 Articles that were selected for review were first screened using SCOPUS and Web of Knowledge
155 searches. These search engines were selected because they have the two most encompassing
156 databases of social and environmental sciences articles (Landauer et al. 2015). We selected only
157 peer-reviewed journal articles. First, the peer-review process of the articles is a measure of quality.
158 Second, we wanted to focus on the state-of-the-art scientific literature on this topic. Third, many of
159 the other sources, such as book chapters, were difficult to obtain. It is also worth pointing out that
160 our selection of the search engines already excluded some gray literature. We acknowledge that this
161 decision might have excluded some relevant documentation but we consider the sample analyzed
162 here to be large enough to gain a systematic overview of the existing literature.

163

164 As the first step, we searched for articles that mention ‘non-climatic factors’. We then performed
165 new searches in which we added new terms because we found early on in the search process that
166 many different notions have been used in literature. Finally, we used the following search sequence:

167

168 ("other pressure*" OR "other risk*" OR "other driver*" OR "other stress*" OR "other
169 factor*" OR "multiple pressure*" OR "multiple risk*" OR "multiple driver*" OR "multiple
170 stress*" OR "multiple factor*" OR "multiple exposure*" OR "double exposure*" OR non-

171 climat*) AND (vulnerab* OR adapt*) AND (climat* OR "environmental change*" OR "global
172 change*")

173

174 These terms were searched from the title, abstract and keywords of the articles. Full text searches
175 were left out since we wanted to find the articles in which climate change and non-climatic factors
176 were pointed as the central focus of the research in the title, abstract and/or keywords. The result
177 included 888 hits from SCOPUS and 836 hits from Web of Knowledge on June 4th 2015. When
178 duplicates were removed, there were 1081 studies left. From this total, the titles, abstracts and, if
179 needed, full texts of all articles were skimmed based on the following criteria.

180

181 We analyzed the quality and relevance of different articles and we selected articles that had a focus
182 on (1) ‘non-climatic factors’ or ‘multiple stressors’ and (2) issues of human vulnerability or
183 adaptation. We did not select studies with a focus on ecology (majority of the excluded articles) or
184 environmental vulnerability without clear links to human vulnerability. We further deselected
185 articles in which the focus was infrastructure, medicine-related, law, economics, highly specific
186 commodity studies, energy policy, archaeology, education, migration or conflict and national
187 security. In addition, we excluded studies in which the main focus was on climate change mitigation
188 efforts or which did not include a clear case study or a review of specific case studies. This
189 selection process left us a total of 125 peer-reviewed, English-written journal articles
190 (Supplementary Material).

191

192 After the article selection process, we analyzed the content of articles using eight guiding questions
193 that were modified from the relevant vulnerability literature. *First*, we evaluated when and where
194 the studies have been conducted. *Second*, we asked what or who is vulnerable (Malone and Engle
195 2011). *Third*, we asked about the source of vulnerability (“vulnerability to what” (Malone and Engle
196 2011)), by examining what kinds of stressors are mentioned in the studies. More specifically, we
197 used the divisions to local/global (internal/external) and cross-scale vulnerability factors and to

198 social, biophysical and integrated vulnerability factors (Füssel 2007). Moreover, with the help of the
199 IPCC climate-related risk framework (IPCC 2014), we analyzed if the stressors have an effect on
200 hazard, exposure or vulnerability. *Fourth*, we further evaluated, how different concepts such as
201 stressor and factor are used and if there are differences between and within different concepts. *Fifth*,
202 based on the distinctions used by O'Brien et al. (2007), we divided the orientation of the studies into
203 outcome-orientation and contextual-orientation. *Sixth*, by analyzing the vulnerability context, we
204 evaluated if the importance of different stressors is assessed as suggested by Bennett et al. (2015a),
205 and how the importance has been assessed. *Seventh*, we examined if the interactions between
206 different stressors and across different scales are examined as suggested by Turner et al. (2003).
207 *Eighth*, in order to further analyze the novelty of 'multiple stressors' approaches, we examined what
208 traditions and articles are cited in the reviewed literature.

209

210 **3 Results and discussion**

211

212 **3.1 When and where the studies were conducted**

213

214 The review shows that there is a significant increase in studies that encompass 'multiple stressors'
215 or non-climatic factors during the last ten years. The number of publications increased after 2006
216 with a peak of publications being 23 (18 %) in 2014. Of the analyzed articles, 79% were published
217 after 2009 (Fig. 1). It has been found also in other reviews that there has been a recent increase in
218 articles looking at vulnerability (McDowell et al. 2016; Wang et al. 2014). In our sample, the
219 number of articles per year has been increasing with one notable exception; in 2011, the amount of
220 articles published was less than half of the amount of articles published in 2010.

221

222 This overall trend reflects the foci of the IPCC assessment reports. For the WG2 AR5 report, studies
223 that were published after October 2006 and accepted for publication (minimum requirement) before

224 August 2013 were considered. Our sample indicates that there were few studies published before
225 October 2006; therefore, there was relatively limited literature considering ‘multiple stressors’ to be
226 considered for the IPCC reports prior to AR5. This result resonates with the latest IPCC report
227 where it was pointed out that the AR5 has overcome limitations evident in AR4 in relation to the
228 research analyzing the human dimensions of climate change (Burkett 2014). Our sample also
229 demonstrates that most of the studies that focus on the various processes that cause vulnerability
230 have been published after some founding papers, where ‘multiple stressors’ and other similar
231 concepts were analyzed explicitly for the first time (O'Brien and Leichenko 2000; O'Brien et al.
232 2004; Tschakert 2007). This result demonstrates that the analysis of other stressors is a relatively
233 new issue within this field of literature.

234

235 In geographical terms, the main focus of the ‘multiple stressors’ studies is in Africa. In 36% of the
236 reviewed articles, the study area or part of the study area was situated in Africa while the rest of the
237 study areas were located in Asia (22%), North America (18%), Latin America (14%), Europe
238 (14%), and Oceania (14%). These numbers do not sum up to 100% since study areas from multiple
239 continents were included in some of the studies.

240

241 **3.2 The object of vulnerability**

242

243 The scope of the study varied in the articles. Majority of the studies evaluated small-scale farming
244 communities in developing countries. Livelihood vulnerability (79%) was the central focus in most
245 of the articles whilst the remainder of the studies analyzed the vulnerability of, for instance,
246 industrial agricultures or wider societal processes. Some of the studies did not particularly analyze
247 vulnerability. For instance, Hageback et al. (2005) examined farmers’ land use decisions, and
248 Coulibaly et al. (2015) the reasons behind crop failure. Whilst not explicitly examining a vulnerable
249 entity, the drivers behind these issues were often similar as the causes of vulnerability.

250

251

3.3 Types of stressors

252

253 Overall, there were hundreds of different stressors mentioned. In our sample, the number of
254 stressors varied between two and 30 within one article. However, it is difficult to explicitly assess
255 the total number of stressors since they were sometimes lumped together or split into smaller
256 entities (for different lists and typologies of stressors, see e.g. (Bennett et al. 2015a; Zou and Wei
257 2010)). Additionally, stressors covered multiple societal scales ranging from lack of local income
258 opportunities or access to local granaries to globalization and global climate change.

259

260 Approximately 25% of the stressors were biophysical while 75% were social. Biophysical stressors
261 identified within the articles were mainly related to natural resource degradation, pollution and pests
262 in addition to climate change and climate-related events such as floods or droughts. Social stressors
263 were mainly related to issues such as poverty, unemployment, health, agricultural markets,
264 governance and globalization. The higher number of social stressors can be due to the fact that
265 social phenomena are more heterogeneous and context-specific.

266

267 The distinction between local and global yet alone to internal and external factors is complicated.
268 What is ‘internal’ depends on how the boundaries of the object of study are drawn. If the object of
269 study is a village, internal stressors are different compared to a study in which the object of study is
270 a country (see Gallopín (2006)). In most of the reviewed studies, the object of study was
271 comparably small, often a community or a set of communities. Nevertheless, in the majority of the
272 studies, most of the stressors were not local, such as global climate change phenomena or global
273 trade tariffs or national subsidies, with little possibilities to alleviate these stressors just within the
274 local context of vulnerability.

275

276 Cross-scale interactions also hampered the classification of stressors into local and global ones.
277 There were some social stressors or those related to local power relations that were more clearly
278 local. However, most of the stressors such as poverty or environmental degradation can be
279 considered as multi-scale stressors that affect human populations across scales (see also Füssel
280 (2007)). It has been suggested that multi-scale governance could remove some barriers between
281 separate scales but challenges of coordinating actions between different scales remain (Næss et al.
282 2005).

283

284 Most of the stressors were considered to have an effect on either hazard or vulnerability. In other
285 words, stressors were hardly ever related to exposure, as considered by IPCC (2014). One reason
286 behind this issue is that exposure, if understood as being merely a spatial concept, is not always
287 relevant. While exposure to floods tends to be reliant on the location, exposure to other hazards or
288 shocks, such as drought or economic recession, is more independent of the location.

289

290 **3.4 The use of different concepts**

291

292 As can be seen from the search terminology, different concepts have been used in the analyses of
293 the effects of non-climatic factors on human vulnerability. Quite expectedly, the concept of
294 vulnerability was used in almost all of the studies (Table 1). Also concepts of risk and factor were
295 widely used. However, key IPCC concept hazard and concepts such as stress and stressor were not
296 used in approximately 30% of the articles. When different concepts were combined with the search
297 words multiple and other, different results were obtained (Table 2). It can be seen that ‘double
298 exposure’, ‘multiple stressors’, ‘other stressors’ and ‘other factors’ together with non-climat* were
299 most widely used; however, these combined concepts were used in less than half of the articles.
300 This shows that none of the concepts is well established to be used widely; furthermore, many of
301 the concepts are used interchangeably.

302

303 The term risk is widely used and in many different contexts in different studies. The IPCC climate
304 risk framework (IPCC 2014) is, however, not used explicitly. One reason behind this is that the
305 framework is new and not yet widely established. Another important reason is that risks have
306 dissimilar components in different studies and many different risks are raised ranging from climate
307 and flood risks to risks related to HIV/AIDS. The term hazard is usually used in the meaning of
308 natural hazards and pointing to single events. Some authors, nevertheless, acknowledge that hazards
309 can be slow changes (McNeeley and Shulski 2011) or equate hazards with political-economic
310 shocks (Shackleton and Shackleton 2012). Similar to risk, the term vulnerability is widely used and
311 often with different meanings without a clear framework.

312

313 The general components of vulnerability (i.e. exposure, sensitivity and adaptive capacity) are rarely
314 analyzed explicitly. An exception is the study by Hjerpe and Glaas (2012) who examine factors that
315 affect exposure, sensitivity and adaptive capacity in terms of flooding vulnerability in southwestern
316 Sweden. The term exposure is not usually used in the same spatial meaning as in the IPCC in the
317 reviewed studies but in a meaning of a manifestation of a hazard. This is actually in line with the
318 older IPCC framework in which exposure is defined as “the nature and degree to which a system is
319 exposed to” shocks and hazards (McCarthy et al. 2001).

320

321 The term ‘double exposure’ refers to two hazards or shocks that together cause risks and
322 vulnerability. In the reviewed literature, ‘double exposure’ was used almost exclusively in this
323 manner, although the concept has been extended to diverse social and environmental changes
324 (McKune and Silva 2013) or broadened to ‘gendered double exposure’ (Nyantakyi-Frimpong and
325 Bezner-Kerr 2015). In addition, the original authors of the ‘double exposure’ concept have later
326 broadened the concept by looking at three pathways of ‘double exposure’, which are outcome
327 (combined impact of processes), context (one process changes the context of the other process and

328 decreases capacity to respond) and feedback (interactions between process impacts and drivers)
329 (Leichenko and O'Brien 2008; Leichenko et al. 2010; O'Brien et al. 2009). The concept of 'multiple
330 exposures' is another extension of the 'double exposure' concept but one that is used slightly
331 differently. For instance, Belliveau et al. (2006) use the term risk as a potential harm, while
332 exposure is a manifestation of this harm (i.e., someone is exposed to a risk). Belliveau et al. (2006)
333 also bring exposure and sensitivity together so that the unit under exposure and its characteristics
334 are evaluated simultaneously. The same kind of terminology is used by Westerhoff and Smit (2009)
335 who employ the term 'multiple exposure-sensitivities'. Other authors such as Bunce et al. (2010)
336 and Bennett et al. (2015b), primarily use the concept of 'multiple stressors' but refer to 'multiple
337 exposures' when the different stressors are manifested. This usage is in accordance with the older
338 IPCC exposure-sensitivity-adaptive capacity vulnerability framework.

339

340 The concept 'multiple stressors' was first used to denote the two phenomena of climate change and
341 globalization that cause 'double exposure' (O'Brien et al. 2004) but the usage of this term has been
342 considerably widened. Stressor is fairly often used synonymously with IPCC's hazard concept but
343 its significance is much broader. For instance, Tschakert (2007) uses terms worry, stress, stressor,
344 hazard and threat interchangeably to denote threats that affect people. Therefore, some of the
345 stressors such as poor health or lack of money used by Tschakert (2007) and also by other authors
346 can be considered merely issues that increase individuals', households' or communities' social
347 vulnerability to hazards rather than hazards per se. Similar issues have been elaborated in social
348 vulnerability literature (Cutter et al. 2003).

349

350 'Factor', 'driver' and 'pressure' further complicate the mixed usage of different concepts. Factor is
351 used in a wide array of meanings: denoting to a statistical connotation, to factors of change, risk
352 factors or more widely to non-climatic factors. Driver is often used to mean the processes that cause
353 changes (drivers of change) and in some cases as a synonym for pressures or stressors (Connolly-

354 Boutin and Smit 2015). Pressure is used in the same way as stressor or in the very wide everyday
355 meaning. For instance, Chandra and Gaganis (2015) use the term ‘non-climatic pressures’ when
356 referring to issues such as tourism, social change and deforestation, while Suckall et al. (2014) use
357 drivers and pressures in the drivers-pressures-states-impacts-response (DPSIR) framework. In this
358 widely used framework, climate change, economic growth and other *drivers* exert *pressures* (e.g.
359 over extraction of resources), which cause changes in *state* (e.g. in livelihoods). These changes are
360 considered *impacts*, which may be alleviated with adaptive and coping *responses*. DPSIR and other
361 frameworks (Bennett et al. 2015a; Hopkins 2015) are used for organizing complex information and
362 simplify the usage of different concepts, which can otherwise be confusing.

363

364 The usage of the term non-climatic illustrates how one concept can be used in various meanings and
365 in different combinations. The term is originally used as denoting other factors than climate that
366 contribute to vulnerability (Füssel and Klein 2006). In the reviewed articles, non-climatic has been
367 used in combination with factor, pressure, risk, determinant of vulnerability, stress, stressor, impact,
368 stimuli, condition, change, force, issue, exposure-sensitivity, variable and driver. All these
369 combinations show that non-climatic can attain many meanings often denoting to hazards or other
370 issues that have an effect on risks or vulnerability. Hence, the term non-climatic is used as a
371 counterpoint to climatic but in different studies the term is used differently.

372

373 Furthermore, the relative importance of non-climatic versus climatic varies in different studies and
374 in different cases. For example, Lereboullet et al. (2014) model the impacts of future climate to
375 viticulture in southern France and use interviews in order to analyze the relative role of non-climatic
376 factors, while McDowell and Hess (2012) analyze the effect of ‘multiple stressors’ on indigenous
377 smallholders on Bolivian highlands using the term ‘non-climatic stressors’ to highlight that not all
378 the stressors are climatic. Whereas the weight is clearly given to climate in the first example,
379 different stressors are considered equally important in the second study. In general, the reviewed

380 studies show that non-climatic and ‘multiple stressors’ do not have different emphasis; rather they
381 illustrate that both concepts are used in versatile ways.

382

383 Overall, our analysis shows that different concepts have been used in a wide range of meanings.

384 One key message is that the different factors cannot be organized to the IPCC framework of

385 hazards, exposure and vulnerability since there is no conceptual clarity of the key concepts among

386 the researchers within this multi-disciplinary field of human dimensions of climate change. Ideally,

387 concepts should be general enough in order to allow their usage in the same meaning across

388 different cases and in different studies. Nevertheless, as Hinkel (2011) suggests, a general definition

389 of vulnerability should be agreed upon but the concept should thereafter be further operationalized

390 based on the conceptual framework used and the context of the case analyzed. In our sample, only a

391 few studies were explicit in how the different concepts were operationalized and on which kind of

392 conceptual framework the studies were based. This mixed usage of concepts and lack of explicit

393 description of frameworks has been found also in a vulnerability review by Delaney et al. (2014).

394

395 This lack of conceptual clarity within the field hinders a better understanding of the dynamics of

396 climate change and human vulnerability. Given the overlapping use of concepts, it is hard to

397 consider to what extent the different non-climatic factors interact or influence each other. There is

398 no abundance of conceptual frameworks or models, par a few examples (e.g. DPSIR), which

399 address this issue and attempt to present a simple model of interactions. Whilst developing even a

400 simplistic framework or model always leads to compromise, it can nevertheless help to clarify some

401 connections within complex system. At the same time we acknowledge that differences between the

402 reviewed studies partly relate to divergences in interpretations that are rooted in different discourses

403 and some of the differences may not be integrated into one common framework (O'Brien et al.

404 2007). More conceptual clarity would nevertheless enable some integration of approaches that are

405 discursively close to each other and also help in bridging the approaches that may fundamentally

406 differ but still complement each other.

407

408 **3.5 Analysis of the vulnerability context**

409

410 We divided the orientation of the studies to outcome-oriented, contextual-oriented and mixed focus
411 using the division by O'Brien et al. (2007). In their distinction, outcome vulnerability is a linear
412 result of projected impacts on the exposed unit, whereas contextual vulnerability builds on a
413 processual and multidimensional approach in which several social, economic, political and
414 institutional structures and conditions also affect vulnerability. They also acknowledge that some
415 approaches lie between the two interpretations of vulnerability and specifically exemplify that
416 'multiple stressors' is an intermediate approach: vulnerability can be an outcome of 'multiple
417 stressors', or 'multiple stressors' can impact the context in which vulnerability is experienced.

418

419 We classified 76 articles (or 61%) as contextual oriented, 32 articles (26%) as outcome focused and
420 17 articles (14%) as mixed. Our analysis thus shows that among climate change literature there is
421 considerable number of studies that analyze the vulnerability context. Furthermore, the number of
422 these studies is rapidly increasing (Fig. 1). Our classification is in line with the analysis of
423 McDowell et al. (2016) but differs from the analysis of Bassett and Fogelman (2013), who stated
424 that 70% of the 558 studies they considered were outcome focused (where the main source of
425 vulnerability was climate impacts), 3% of the studies focused on social roots of the vulnerability
426 and 27 % considered both.

427

428 This disparity results from many reasons. First and foremost, the sample of the studies between the
429 reviews differs. Our review was systematic and we selected articles using systematic searches as
430 recommended by Lorenz et al. (2014), while Bassett and Fogelman (2013) chose four journals and
431 used only one search word: *adaptation*. The article search process was different and our search

432 words could have favored contextual vulnerability or mixed-focus studies. Second, we selected only
433 studies with clear focus on human vulnerability, whereas Bassett and Fogelman (2013) did not carry
434 out the further pruning of the studies. Third, we classified all the studies where there is a clear
435 analysis of the vulnerability context as contextual. In our view, most of these studies would have
436 been classified as mixed in the analysis by Bassett and Fogelman (2013). Fourth, many of the
437 studies in our analysis were published after 2012 the time when the Bassett and Fogelman (2013)
438 article was submitted for the review.

439

440 **3.6 Importance of stressors**

441

442 Quite often, the reviewed articles claimed that climate was not the most important factor or not the
443 most pressing stressor affecting vulnerability (Table 3). In 44 (35%) of the 125 studies analyzed,
444 there was no indication of which the most important stressors are. The rest of the studies were
445 divided into two parts: half ranked climate-related stressors such as drought as the most important,
446 and the other half stressors other than climate as the most important. Stressors other than climate
447 included social issues such as lack of income or capital, health, governance, neoliberalism or
448 globalization and demographics.

449

450 As this list suggests, stressors can be found at different scales. While some of the stressors, such as
451 lack of income or poor health, have an effect on everyday lives, other stressors, such as climate
452 change and globalization, are global-scale forces that might exert an effect on more proximate
453 stressors. This indicates interconnectedness of stressors across different scales. Many of the
454 stressors are also fairly heterogeneous and their impacts can vary depending on the context. For
455 instance, while in a remote community in the Norwegian Arctic primary stressor for community
456 adaptation is population decline (Amundsen 2012), in many other contexts one of the major stresses
457 concerning the adaptation to climate change is caused by population growth (Fazey et al. 2011;

458 Laube et al. 2012; Pricope et al. 2013).

459

460 In the reviewed literature, the relative importance of different stressors was analyzed by methods of
461 interviews, participatory approaches and surveys, by judgments made by researchers, by focusing
462 on some stressor(s) and by modeling or by combining different approaches. All these different
463 methodological approaches yield varying results (Table 3). When importance was examined based
464 on data gathered by interviews, surveys or participatory methods, 41% of studies ranked climate as
465 the most important stressor but more articles ranked climate as the most important when importance
466 was evaluated by researchers' judgment (57%) or selection of focus (83%).

467

468 In addition, there were differences in how the evaluations were made or how the interviews were
469 carried out. These interlinked with the conceptual issues of how the object of vulnerability was
470 defined, what the important stressors were considered to be, at what scales they were analyzed and
471 how the interviews and their analyses were framed. Different sorts of stressors were often included
472 in the same analysis. In many of the reviewed studies which were based on interviews most
473 important stressors were considered to be everyday distress or everyday worries. In future, we
474 suggest using triangulation and cross-checking in data interpretation to sort out the importance of
475 stressors at different scales and to examine how stressors might be interlinked. Better explanation of
476 the conceptual framework used would also be important.

477

478 Our review indicates that there are complex interconnections between climatic and non-climatic
479 factors concerning the human vulnerability and climate change. First, climatic factors cannot be
480 analyzed in isolation because other stressors shape the context, in which climate change is
481 experienced (Eriksen et al. 2011; O'Brien et al. 2007). Furthermore, especially in many parts of the
482 global South, adaptation and mitigation policies themselves can sometimes cause further
483 vulnerabilities (Bose 2015). Second, other stressors affect the vulnerability of especially those

484 communities and groups of population that are already experiencing high levels of vulnerability.
485 These communities might become even more vulnerable in the future when the impacts of climate
486 change become more evident. In order to decrease vulnerability, the context of ‘multiple stressors’
487 should be taken into account; and the vulnerability to different stressors should be reduced (Eriksen
488 et al. 2011; McCubbin et al. 2015).

489

490 **3.7 Analysis of interactions**

491

492 O'Brien et al. (2009) highlight that ‘multiple stressors’ literature should analyze interactions
493 between different stressors. Interactions were mentioned or acknowledged in 95 (76% of the
494 studies) of the reviewed studies. However, only 35 (28%) of the studies included explicit analysis of
495 the interactions as also found by Tucker et al. (2014).

496

497 If there is no clear analysis how the different stressors interact and intertwine, the relative
498 importance of different stressors is difficult to assess. For instance, climate change is often a part of
499 the cause for the most proximate and more evident stressors (see e.g. McCubbin et al. (2015)). This
500 was stressed not only in the studies where importance was assessed using researchers’ judgments
501 but also by interviewees (Mubaya et al. 2012; Petheram et al. 2010).

502

503 The interconnections between different stressors and different scales also complicate the division
504 between social and biophysical factors, as well as between local and global processes. For instance,
505 Reenberg et al. (2012) report that in the Sahel area, drought (non-local biophysical stressor) forced
506 young men to migrate periodically to find pastures elsewhere. This resulted in lack of labor (local
507 social stressor) and bottlenecks in agricultural production in the next growing season.

508

509 Therefore, it is more important to analyze the interactions and cause-response relationships between

510 different stressors than to divide them to different groups. Interacting stressors and associated
511 processes are also dynamic: they change over time and context and across scales. Some authors
512 (Belliveau et al. 2006; Westerhoff and Smit 2009) have thus used the concept of ‘dynamic
513 vulnerability’ to emphasize the changing environment and interacting stressors. In future studies, we
514 recommend together with other scholars (Bennett et al. 2015a; Bennett et al. 2015b; Tucker et al.
515 2014) a clear analysis or at least brief exploration of interactions. The analysis of interactions also
516 helps in distinguishing stressors that act at different scales.

517

518 **3.8 Different scientific traditions**

519

520 Multiple stressors have been studied in many scientific traditions such as climate research and
521 hazard research. It has been argued that multiple stressors have been examined for decades in the
522 latter tradition (see Introduction Section). In our sample, only one (Smit et al. 1996) of the papers
523 was published before the 2000s. This suggests that studies of ‘multiple stressors’ is a relatively new
524 research interest. However, previous studies might have used other terms than the ones we used in
525 our literature searches. Thus, it is possible that we might have missed some studies that did not
526 focus on climate change specifically but belonged to other scientific traditions such as hazards
527 research.

528

529 In most of the reviewed articles, early studies of ‘multiple stressors’ analysis were not cited
530 exhaustively, though many of the studies such as Lopez-Marrero and Yarnal (2010), Prno et al.
531 (2011) and O'Brien et al. (2009) refer to the earlier traditions such as literature on hazards (Wisner
532 et al. 2004) or social vulnerability (Cutter et al. (2003). In general, it was argued that the earlier
533 papers were merely theoretical, whereas the newer literature either represents empirical case studies
534 or analyzes interactions between different stressors. There are also authors such as Smit et al.
535 (1996) and Smit and Skinner (2002), who acknowledge that there have been studies within other

536 fields such as agricultural systems analysis where multiple factors have been considered but in
537 many of these studies *ceteris paribus* assumptions have been made. The lack of citation to earlier
538 traditions illustrates perhaps a discontinuity within research traditions and presents a risk of
539 reinventing the wheel, conceptually and methodologically. Nevertheless, a recent bibliometric
540 analysis found some evidence of convergence between different traditions (Giupponi and Biscaro
541 2015).

542

543 **4 Conclusions**

544

545 We systematically reviewed climate change literature in which ‘multiple stressors’ or ‘non-climatic
546 factors’ have been accounted for. We chose articles for the review with the help of SCOPUS and
547 Web of Knowledge searches with different keywords. Our searches left out some articles which
548 consider ‘multiple stressors’ (Adelekan and Fregene 2015; Amoako Johnson and Hutton 2014;
549 McDowell et al. 2016) but our systematic sample consisted of 125 articles. We have contributed to
550 the conceptual clarity of an emerging new field of research on vulnerability that endorses various
551 processes interacting with climate change. Based on our results, following three major conclusions
552 can be drawn.

553

554 First, the analysis of ‘multiple stressors’ is a relatively new field with literature expanding
555 especially since 2010. Although the analysis of ‘multiple stressors’ builds on earlier literature about
556 hazards, it has made the understanding more profound by using empirical case studies and in some
557 cases by analyzing interactions between different stressors. We recommend that in further studies
558 interactions should be better analyzed to clearly demonstrate which stressors should be targeted
559 simultaneously.

560

561 Second, the literature about ‘multiple stressors’ is heterogeneous. Whilst some of the found
562 differences in part relate to differences in interpretations that are rooted in different discourses,

563 many of the studies are not explicit about the interpretations and conceptualizations they use (see
564 Section The use of different concepts). More conceptual clarity would enable some integration of
565 approaches and also help in bridging the approaches that may fundamentally differ but still
566 complement each other. We recommend usage of analytical frameworks or models which specify
567 differences, interactions and relationships between different drivers, processes and stressors.

568

569 Third, it was often stressed that climate change is not the most evident stressor. This was
570 emphasized 59% of the studies where results were obtained using interviews or surveys. This is
571 logical since climate change is only one of the stressors affecting people's everyday lives and it is
572 not always prioritized in policy implementation. The importance of different stressors is difficult to
573 measure or rank due to interactions between different stressors and changes in time, context and
574 across scales; therefore, we recommend use of mixed methods and triangulation of different data
575 sources in the data analysis to sort out the most important stressors.

576

577 The reviewed literature emphasizes that there are multiple interacting stressors that should be
578 analyzed together and these stressors should be targeted by policies, which integrate adaptation to
579 climate change and other stressors. Risks related to climate change are not caused by climate
580 change alone but by various intertwining biophysical and social drivers and stressors, which have
581 effects on hazards, exposure and vulnerability. Finally, the way vulnerability is conceptualized and
582 approached in research has also relevant policy implications. The different definitions of problems
583 and their consequences outline and justify different kind of policy responses and lead to different
584 kind of operationalization of vulnerability assessments in the adaptation policies. The framings of
585 vulnerability thus have very material effects on the well-being of vulnerable and disadvantaged
586 social groups.

587

588

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595

596 **References**

- 597 Adelekan I, Fregene T (2015) Vulnerability of artisanal fishing communities to flood risks in coastal
 598 southwest Nigeria *Climate and Development* 7:322-338 doi:10.1080/17565529.2014.951011
- 599 Adger WN (2006) Vulnerability Global Environmental Change-Human and Policy Dimensions
 600 16:268-281 doi:10.1016/j.gloenvcha.2006.02.006
- 601 Amoako Johnson F, Hutton CW (2014) Dependence on agriculture and ecosystem services for
 602 livelihood in Northeast India and Bhutan: vulnerability to climate change in the Tropical
 603 River Basins of the Upper Brahmaputra *Climatic Change* 127:107-121 doi:10.1007/s10584-
 604 012-0573-7
- 605 Amundsen H (2012) Illusions of Resilience? An Analysis of Community Responses to Change in
 606 Northern Norway *Ecology and Society* 17 doi:10.5751/es-05142-170446
- 607 Bassett TJ, Fogelman C (2013) Deja vu or something new? The adaptation concept in the climate
 608 change literature *Geoforum* 48:42-53 doi:10.1016/j.geoforum.2013.04.010
- 609 Belliveau S, Smit B, Bradshaw B (2006) Multiple exposures and dynamic vulnerability: Evidence
 610 from the grape industry in the Okanagan Valley, Canada *Global Environmental Change-
 611 Human and Policy Dimensions* 16:364-378 doi:10.1016/j.gloenvcha.2006.03-003
- 612 Bennett NJ, Blythe JL, Tyler S, Ban NC (2015a) Communities and change in the anthropocene:
 613 understanding social-ecological vulnerability and planning adaptations to multiple
 614 interacting exposures *Regional Environmental Change* doi:DOI 10.1007/s10113-015-0839-5
- 615 Bennett NJ, Dearden P, Peredo AM (2015b) Vulnerability to multiple stressors in coastal
 616 communities: a study of the Andaman coast of Thailand *Climate and Development* 7:124-
 617 141 doi:10.1080/17565529.2014.886993
- 618 Berrang-Ford L, Pearce T, Ford JD (2015) Systematic review approaches for climate change
 619 adaptation research *Regional Environmental Change* 15:755-769 doi:10.1007/s10113-014-
 620 0708-7
- 621 Berry PM, Rounsevell MDA, Harrison PA, Audsley E (2006) Assessing the vulnerability of
 622 agricultural land use and species to climate change and the role of policy in facilitating
 623 adaptation *Environmental Science and Policy* 9:189-204 doi:10.1016/j.envsci.2005.11.004
- 624 Birkmann J (2006) Measuring vulnerability to promote disaster-resilient societies: Conceptual
 625 frameworks and definitions. In: Birkmann J (ed) *Measuring Vulnerability to Natural
 626 Hazards: Towards Disaster Resilient Societies*. United Nations University Press, Tokyo,
 627 Japan, pp 9-54
- 628 Bose PS (2015) Vulnerabilities and displacements: Adaptation and mitigation to climate change as a
 629 new development mantra *Area* doi:10.1111/area.12178
- 630 Bunce M, Rosendo S, Brown K (2010) Perceptions of climate change, multiple stressors and
 631 livelihoods on marginal African coasts *Environment, Development and Sustainability*

632 12:407-440 doi:10.1007/s10668-009-9203-6

633 Burkett VR, Suarez, A.G., Bindi, M., Conde, C., Mukerji, R., Prather, M.J., St. Clair, A.L. & Yohe,

634 G.W. (2014) Point of Departure. In: Field CB, V.R. Barros, D.J. Dokken, K.J. Mach, M.D.

635 Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S.

636 Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (ed) Climate Change

637 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.

638 Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental

639 Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and

640 New York, NY, USA, pp 169-194

641 Chandra A, Gaganis P (2015) Deconstructing vulnerability and adaptation in a coastal river basin

642 ecosystem: a participatory analysis of flood risk in Nadi, Fiji Islands Climate and

643 Development doi:10.1080/17565529.2015.1016884

644 Connolly-Boutin L, Smit B (2015) Climate change, food security, and livelihoods in sub-Saharan

645 Africa Regional Environmental Change doi:10.1007/s10113-015-0761-x

646 Coulibaly JY, Gbetibouo GA, Kundhlande G, Sileshi GW, Beedy TL (2015) Responding to Crop

647 Failure: Understanding Farmers' Coping Strategies in Southern Malawi Sustainability

648 7:1620-1636 doi:10.3390/su7021620

649 Cutter SL, Boruff BJ, Shirley WL (2003) Social vulnerability to environmental hazards Social

650 Science Quarterly 84:242-261 doi:10.1111/1540-6237.8402002

651 Delaney A, Chesterman S, Crane TA, Tamás PA, Erickson P (2014) A systematic review of local

652 vulnerability to climate change: in search of transparency, coherence and comparability vol

653 97. CGIAR Research Program on Climate Change, Agriculture and Food Security

654 (CCAFS),

655 Dessai S, Hulme M (2004) Does climate adaptation policy need probabilities? Climate Policy

656 4:107-128 doi:10.1080/14693062.2004.9685515

657 Eakin H, Luers AL (2006) Assessing the vulnerability of social-environmental systems vol 31.

658 doi:10.1146/annurev.energy.30.050504.144352

659 Eriksen S et al. (2011) When not every response to climate change is a good one: Identifying

660 principles for sustainable adaptation Climate and Development 3:7-20

661 doi:10.3763/cdev.2010.0060

662 Fazey I, Pettorelli N, Kenter J, Wagatora D, Schuett D (2011) Maladaptive trajectories of change in

663 Makira, Solomon Islands Global Environmental Change-Human and Policy Dimensions

664 21:1275-1289 doi:10.1016/j.gloenvcha.2011.07.006

665 Füssel H-M (2007) Vulnerability: A generally applicable conceptual framework for climate change

666 research Global Environmental Change-Human and Policy Dimensions 17:155-167

667 doi:10.1016/j.gloenvcha.2006.05.002

668 Füssel H-M, Klein RJT (2006) Climate change vulnerability assessments: An evolution of

669 conceptual thinking Climatic Change 75:301-329 doi:10.1007/s10584-006-0329-3

670 Gallopín GC (2006) Linkages between vulnerability, resilience, and adaptive capacity Global

671 Environmental Change 16:293-303 doi:10.1016/j.gloenvcha.2006.02.004

672 Giupponi C, Biscaro C (2015) Vulnerabilities - Bibliometric analysis and literature review of

673 evolving concepts Environmental Research Letters 10 doi:10.1088/1748-9326/10/12/123002

674 Hageback J, Sundberg J, Ostwald M, Chen D, Yun X, Knutsson P (2005) Climate variability and

675 land-use change in Danangou watershed, China - Examples of small-scale farmers'

676 adaptation Climatic Change 72:189-212 doi:10.1007/s10584-005-5384-7

677 Hashimoto M, Styrikovick M, Nishioka S, al. e (1990) Chapter 5. Human settlement; the energy,

678 transport and industrial sectors; human health; air quality; and changes in ultraviolet-B

679 radiation. In: Tegart W. J. McG. SGWaDCG (ed) Climate Change: The IPCC Impacts

680 Assessment. Australian Government Publishing Service, Canberra,

681 Hinkel J (2011) "Indicators of vulnerability and adaptive capacity": Towards a clarification of the

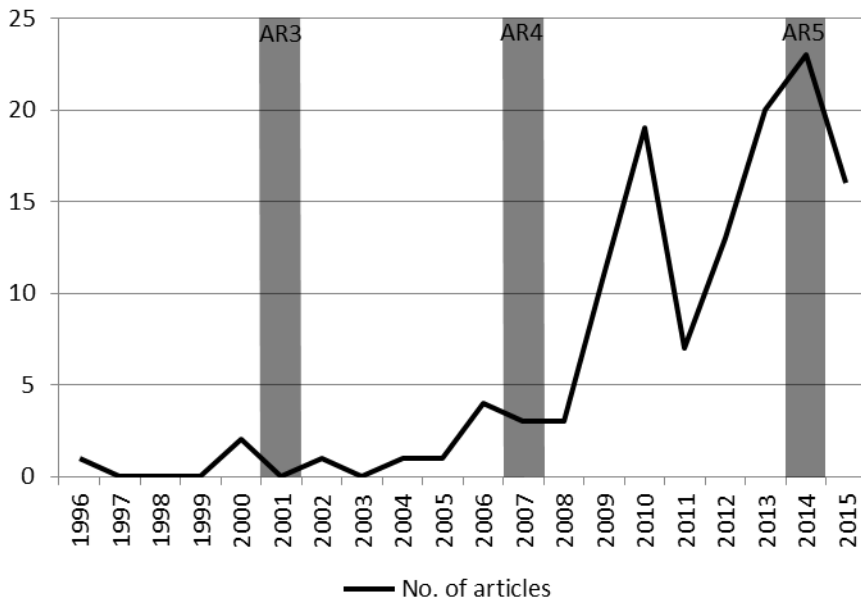
682 science-policy interface Global Environmental Change-Human and Policy Dimensions

683 21:198-208 doi:10.1016/j.gloenvcha.2010.08.002

- 684 Hjerpe M, Glaas E (2012) Evolving local climate adaptation strategies: incorporating influences of
685 socio-economic stress *Mitigation and Adaptation Strategies for Global Change* 17:471-486
686 doi:10.1007/s11027-011-9337-3
- 687 Hopkins D (2015) Applying a Comprehensive Contextual Climate Change Vulnerability
688 Framework to New Zealand's Tourism Industry *Ambio* 44:110-120 doi:10.1007/s13280-014-
689 0525-8
- 690 IPCC (2007) Summary for Policymakers. In: M.L. Parry OFC, J.P. Palutikof, P.J. van der Linden
691 and C.E. Hanson (ed) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, pp 7-22
- 692
693
694 IPCC (2014) Summary for policymakers. In: Field CB, V.R. Barros, D.J. Dokken, K.J. Mach, M.D.
695 Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S.
696 Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (ed) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and
697
698
699
700 New York, NY, USA, pp 1-32
- 701 Kelly PM, Adger WN (2000) Theory and practice in assessing vulnerability to climate change and
702 facilitating adaptation *Climatic Change* 47:325-352 doi:10.1023/a:1005627828199
- 703 Kelman I, Gaillard JC, Mercer J (2015) Climate Change's Role in Disaster Risk Reduction's Future:
704 Beyond Vulnerability and Resilience *International Journal of Disaster Risk Science* 6:21-27
705 doi:10.1007/s13753-015-0038-5
- 706 Landauer M, Juhola S, Söderholm M (2015) Inter-relationships between adaptation and mitigation:
707 a systematic literature review *Climatic Change* doi:10.1007/s10584-015-1395-1
- 708 Laube W, Schraven B, Awo M (2012) Smallholder adaptation to climate change: dynamics and
709 limits in Northern Ghana *Climatic Change* 111:753-774 doi:10.1007/s10584-011-0199-1
- 710 Leichenko R, O'Brien K (2008) Environmental Change and Globalization: Double Exposures.
711 *Environmental Change and Globalization: Double Exposures*.
712 doi:10.1093/acprof:oso/9780195177329.001.0001
- 713 Leichenko R, O'Brien K, Solecki W (2010) Climate Change and the Global Financial Crisis: A Case
714 of Double Exposure *Annals of the Association of American Geographers* 100:963-972
715 doi:10.1080/00045608.2010.497340
- 716 Lereboullet A-L, Beltrando G, Bardsley DK, Rouvellac E (2014) The viticultural system and
717 climate change: coping with long-term trends in temperature and rainfall in Roussillon,
718 France *Regional Environmental Change* 14:1951-1966 doi:10.1007/s10113-013-0446-2
- 719 Lopez-Marrero T, Yarnal B (2010) Putting adaptive capacity into the context of people's lives: a
720 case study of two flood-prone communities in Puerto Rico *Natural Hazards* 52:277-297
721 doi:10.1007/s11069-009-9370-7
- 722 Lorenz S, Berman R, Dixon J, Lebel S (2014) Time for a systematic review: A response to Bassett
723 and Fogelman's "Déjà vu or something new? The adaptation concept in the climate change
724 literature" *Geoforum* 51:252-255 doi:10.1016/j.geoforum.2013.10.003
- 725 Malone EL, Engle NL (2011) Evaluating regional vulnerability to climate change: purposes and
726 methods *Wiley Interdisciplinary Reviews-Climate Change* 2:462-474 doi:10.1002/wcc.116
- 727 McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) (2001) *Climate Change 2001:
728 Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third
729 Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge
730 University Press, Cambridge, UK
- 731 McCubbin S, Smit B, Pearce T (2015) Where does climate fit? Vulnerability to climate change in
732 the context of multiple stressors in Funafuti, Tuvalu *Global Environmental Change-Human
733 and Policy Dimensions* 30:43-55 doi:10.1016/j.gloenvcha.2014.10.007
- 734 McDowell G, Ford J, Jones J (2016) Community-level climate change vulnerability research:
735 trends, progress, and future directions *Environmental Research Letters* 11:033001

- 736 doi:10.1088/1748-9326/11/3/033001
- 737 McDowell JZ, Hess JJ (2012) Accessing adaptation: Multiple stressors on livelihoods in the
738 Bolivian highlands under a changing climate *Global Environmental Change-Human and*
739 *Policy Dimensions* 22:342-352 doi:10.1016/j.gloenvcha.2011.11.002
- 740 McKune SL, Silva JA (2013) Pastoralists under Pressure: Double Exposure to Economic and
741 Environmental Change in Niger *Journal of Development Studies* 49:1711-1727
742 doi:10.1080/00220388.2013.822067
- 743 McLaughlin P, Dietz T (2008) Structure, agency and environment: Toward an integrated perspective
744 on vulnerability *Global Environmental Change* 18:99-111
745 doi:10.1016/j.gloenvcha.2007.05.003
- 746 McNeeley SM, Shulski MD (2011) Anatomy of a closing window: Vulnerability to changing
747 seasonality in Interior Alaska *Global Environmental Change-Human and Policy Dimensions*
748 21:464-473 doi:10.1016/j.gloenvcha.2011.02.003
- 749 Mechler R, Bouwer LM, Linnerooth-Bayer J, Hochrainer-Stigler S, Aerts JCJH, Surminski S,
750 Williges K (2014) Managing unnatural disaster risk from climate extremes *Nature Climate*
751 *Change* 4:235-237 doi:10.1038/nclimate2137
- 752 Mubaya CP, Njuki J, Mutsvangwa EP, Mugabe FT, Nanjad D (2012) Climate variability and change
753 or multiple stressors? Farmer perceptions regarding threats to livelihoods in Zimbabwe and
754 Zambia *Journal of Environmental Management* 102:9-17
755 doi:10.1016/j.jenvman.2012.02.005
- 756 Næss LO, Bang G, Eriksen S, Vevatne J (2005) Institutional adaptation to climate change: Flood
757 responses at the municipal level in Norway *Global Environmental Change* 15:125-138
758 doi:10.1016/j.gloenvcha.2004.10.003
- 759 Nyantakyi-Frimpong H, Bezner-Kerr R (2015) The relative importance of climate change in the
760 context of multiple stressors in semi-arid Ghana *Global Environmental Change* 32:40-56
761 doi:10.1016/j.gloenvcha.2015.03.003
- 762 O'Brien K, Eriksen S, Nygaard LP, Schjolden A (2007) Why different interpretations of
763 vulnerability matter in climate change discourses *Climate Policy* 7:73-88
764 doi:10.1080/14693062.2007.9685639
- 765 O'Brien K, Leichenko R (2000) Double exposure: assessing the impacts of climate change within
766 the context of economic globalization *Global Environmental Change-Human and Policy*
767 *Dimensions* 10:221-232 doi:10.1016/s0959-3780(00)00021-2
- 768 O'Brien K et al. (2004) Mapping vulnerability to multiple stressors: climate change and
769 globalization in India *Global Environmental Change-Human and Policy Dimensions*
770 14:303-313 doi:10.1016/j.gloenvcha.2004.01.001
- 771 O'Brien K, Quinlan T, Ziervogel G (2009) Vulnerability interventions in the context of multiple
772 stressors: lessons from the Southern Africa Vulnerability Initiative (SAVI) *Environmental*
773 *Science & Policy* 12:23-32 doi:10.1016/j.envsci.2008.10.008
- 774 Petheram L, Zander KK, Campbell BM, High C, Stacey N (2010) 'Strange changes': Indigenous
775 perspectives of climate change and adaptation in NE Arnhem Land (Australia) *Global*
776 *Environmental Change-Human and Policy Dimensions* 20:681-692
777 doi:10.1016/j.gloenvcha.2010.05.002
- 778 Pricope NG, Husak G, Lopez-Carr D, Funk C, Michaelsen J (2013) The climate-population nexus
779 in the East African Horn: Emerging degradation trends in rangeland and pastoral livelihood
780 zones *Global Environmental Change-Human and Policy Dimensions* 23:1525-1541
781 doi:10.1016/j.gloenvcha.2013.10.002
- 782 Prno J, Bradshaw B, Wandel J, Pearce T, Smit B, Tozer L (2011) Community vulnerability to
783 climate change in the context of other exposure-sensitivities in Kugluktuk, Nunavut *Polar*
784 *Research* 30 doi:10.3402/polar.v30i0.7363
- 785 Reenberg A, Rasmussen LV, Nielsen JO (2012) Causal relations and land use transformation in the
786 Sahel: conceptual lenses for processes, temporal totality and inertia *Geografisk Tidsskrift-*
787 *Danish Journal of Geography* 112:159-173 doi:10.1080/00167223.2012.741888

- 788 Ribot J (2014) Cause and response: vulnerability and climate in the Anthropocene *Journal of*
789 *Peasant Studies* 41:667-705 doi:10.1080/03066150.2014.894911
- 790 Shackleton SE, Shackleton CM (2012) Linking poverty, HIV/AIDS and climate change to human
791 and ecosystem vulnerability in southern Africa: consequences for livelihoods and
792 sustainable ecosystem management *International Journal of Sustainable Development and*
793 *World Ecology* 19:275-286 doi:10.1080/13504509.2011.641039
- 794 Smit B, McNabb D, Smithers J (1996) Agricultural adaptation to climatic variation *Climatic*
795 *Change* 33:7-29 doi:10.1007/bf00140511
- 796 Smit B, Skinner MW (2002) Adaptation options in agriculture to climate change: A typology
797 *Mitigation and Adaptation Strategies for Global Change* 7:85-114
798 doi:10.1023/a:1015862228270
- 799 Suckall N, Tompkins E, Stringer L (2014) Identifying trade-offs between adaptation, mitigation and
800 development in community responses to climate and socio-economic stresses: Evidence
801 from Zanzibar, Tanzania *Applied Geography* 46:111-121 doi:10.1016/j.apgeog.2013.11.005
- 802 Tschakert P (2007) Views from the vulnerable: Understanding climatic and other stressors in the
803 Sahel *Global Environmental Change-Human and Policy Dimensions* 17:381-396
804 doi:10.1016/j.gloenvcha.2006.11.008
- 805 Tucker J, Daoud M, Oates N, Few R, Conway D, Mtisi S, Matheson S (2014) Social vulnerability in
806 three high-poverty climate change hot spots: What does the climate change literature tell us?
807 *Regional Environmental Change* doi:10.1007/s10113-014-0741-6
- 808 Turner BL et al. (2003) A framework for vulnerability analysis in sustainability science *Proceedings*
809 *of the National Academy of Sciences of the United States of America* 100:8074-8079
810 doi:10.1073/pnas.1231335100
- 811 Wang B, Pan SY, Ke RY, Wang K, Wei YM (2014) An overview of climate change vulnerability: A
812 bibliometric analysis based on Web of Science database *Natural Hazards* 74:1649-1666
813 doi:10.1007/s11069-014-1260-y
- 814 Westerhoff L, Smit B (2009) The rains are disappointing us: dynamic vulnerability and adaptation
815 to multiple stressors in the Afram Plains, Ghana *Mitigation and Adaptation Strategies for*
816 *Global Change* 14:317-337 doi:10.1007/s11027-008-9166-1
- 817 Wisner B, Blaikie P, Cannon T, Davis I (2004) *At Risk* Second edition: Natural hazards, people's
818 vulnerability and disasters. Routledge, London, UK
- 819 Wolf S, Hinkel J, Hallier M, Bisaro A, Lincke D, Ionescu C, Klein RJT (2013) Clarifying
820 vulnerability definitions and assessments using formalisation *International Journal of*
821 *Climate Change Strategies and Management* 5:54-70 doi:10.1108/17568691311299363
- 822 Zou L-L, Wei Y-M (2010) Driving factors for social vulnerability to coastal hazards in Southeast
823 Asia: results from the meta-analysis *Natural Hazards* 54:901-929 doi:10.1007/s11069-010-
824 9513-x
- 825



827

Figure 1. The amount of articles that were selected for the review, published each year. The publishing years of IPCC Working Group 2 Assessment Reports (AR) are marked with transparent gray. Because the literature search was performed on June 4th 2015, the amount of articles published in 2015 is not comparable to other years.

828

Table 1. Different concepts, the percentage of articles in which these concepts were used, and how many times these concepts were overall used in the reviewed articles. Concepts were sought from full-texts including references. All concepts were sought both in singular and in plural form. The overall number of words might not be exact due to problems in character recognition, but their order of magnitude is correct.

Concept	% of articles	Overall
Vulnerability	98 %	4487
Risk	97 %	2561
Factor	97 %	1278
Exposure	83 %	1126
Stress	73 %	1011
Stressor	70 %	1185
Pressure	69 %	342
Hazard	65 %	756
Driver	63 %	502
Sensitivity	58 %	520

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831 *Table 2. Different concepts and the percentage of articles in which these concepts were used.*

832 *Concepts were sought from full-text articles excluding references. All concepts were sought both in*

833 *singular and in plural form.*

Concept	% of articles
non-climat*	40 %
multiple stressor	38 %
other factor	37 %
double exposure	27 %
other stressor	27 %
multiple exposure	12 %
multiple stress	12 %
other stress	11 %
multiple factor	10 %
other risk	10 %
other driver	6 %
multiple risk	6 %
multiple driver	5 %
multiple pressure	3 %
other pressure	0 %

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Table 3. Ranking of the most important stressor based on different analysis method. For each analysis method, and overall, the amount and proportion of articles are given.

Analysis method	Number of articles	Most important stressor	
		Climate	Not climate
Interviews, participatory approaches, surveys	37 (46%)	15 (41%)	22 (59%)
Researchers' judgment	23 (28%)	13 (57%)	10 (43%)
Focusing on some stressors	6 (7%)	5 (83%)	1 (17%)
Modelling	1 (1%)	1 (100%)	0 (0%)
Combination of two or three approaches	14 (17%)	4 (29%)	10 (71%)
Overall	81 (100%)	38 (47%)	43 (53%)

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839 **Climate change, multiple stressors and human vulnerability – a systematic**
840 **review**

841 Regional Environmental Change

842

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846 aleksi.rasanen@helsinki.fi

847 **Supplementary material: Reviewed articles**

848 Amundsen H (2012) Illusions of Resilience? An Analysis of Community Responses to Change in
849 Northern Norway Ecology and Society 17 doi:10.5751/es-05142-170446

850 Andersson E, Gabrielsson S (2012) 'Because of poverty, we had to come together': collective action
851 for improved food security in rural Kenya and Uganda International Journal of Agricultural
852 Sustainability 10:245-262 doi:10.1080/14735903.2012.666029

853 Ashraf M, Routray JK (2013) Perception and understanding of drought and coping strategies of
854 farming households in north-west Balochistan International Journal of Disaster Risk
855 Reduction 5:49-60 doi:10.1016/j.ijdr.2013.05.002

856 Bacon CM, Sundstrom WA, Gomez MEF, Mendez VE, Santos R, Goldoftas B, Dougherty I (2014)
857 Explaining the 'hungry farmer paradox': Smallholders and fair trade cooperatives navigate
858 seasonality and change in Nicaragua's corn and coffee markets Global Environmental
859 Change-Human and Policy Dimensions 25:133-149 doi:10.1016/j.gloenvcha.2014.02.005

860 Bardaji I, Iraizoz B (2014) Uneven responses to climate and market influencing the geography of
861 high-quality wine production in Europe Regional Environmental Change
862 doi:10.1007/s10113-014-0623-y

863 Beilin R, Sysak T, Hill S (2012) Farmers and perverse outcomes: The quest for food and energy
864 security, emissions reduction and climate adaptation Global Environmental Change-Human
865 and Policy Dimensions 22:463-471 doi:10.1016/j.gloenvcha.2011.12.003

866 Belliveau S, Smit B, Bradshaw B (2006) Multiple exposures and dynamic vulnerability: Evidence
867 from the grape industry in the Okanagan Valley, Canada Global Environmental Change-
868 Human and Policy Dimensions 16:364-378 doi:10.1016/j.gloenvcha.2006.03-003

869 Below TB, Schmid JC, Sieber S (2014) Farmers' knowledge and perception of climatic risks and
870 options for climate change adaptation: a case study from two Tanzanian villages Regional
871 Environmental Change doi:10.1007/s10113-014-0620-1

872 Bennett NJ, Dearden P, Peredo AM (2015) Vulnerability to multiple stressors in coastal
873 communities: a study of the Andaman coast of Thailand Climate and Development 7:124-
874 141 doi:10.1080/17565529.2014.886993

875 Birk T (2014) Assessing vulnerability to climate change and socioeconomic stressors in the Reef
876 Islands group, Solomon Islands Geografisk Tidsskrift-Danish Journal of Geography 114:59-
877 75 doi:10.1080/00167223.2013.878228

878 Blythe JL, Murray G, Flaherty M (2014) Strengthening threatened communities through adaptation:

- 879 insights from coastal Mozambique *Ecology and Society* 19 doi:10.5751/es-06408-190206
- 880 Boissiere M, Locatelli B, Sheil D, Padmanaba M, Sadjudin E (2013) Local Perceptions of Climate
- 881 Variability and Change in Tropical Forests of Papua, Indonesia *Ecology and Society* 18
- 882 doi:10.5751/es-05822-180413
- 883 Brklacich M (2006) Advancing our understanding of the vulnerability of farming to climate change
- 884 *Erde* 137:181-198
- 885 Bunce M, Brown K, Rosendo S (2010) Policy misfits, climate change and cross-scale vulnerability
- 886 in coastal Africa: how development projects undermine resilience *Environmental Science &*
- 887 *Policy* 13:485-497 doi:10.1016/j.envsci.2010.06.003
- 888 Bunce M, Rosendo S, Brown K (2010) Perceptions of climate change, multiple stressors and
- 889 livelihoods on marginal African coasts *Environment, Development and Sustainability*
- 890 12:407-440 doi:10.1007/s10668-009-9203-6
- 891 Burton RJF, Peoples S (2014) Market liberalisation and drought in New Zealand: A case of 'double
- 892 exposure' for dryland sheep farmers? *Journal of Rural Studies* 33:82-94
- 893 doi:10.1016/j.jrurstud.2013.11.002
- 894 Casale M, Drimie S, Quinlan T, Ziervogel G (2010) Understanding vulnerability in southern Africa:
- 895 comparative findings using a multiple-stressor approach in South Africa and Malawi
- 896 *Regional Environmental Change* 10:157-168 doi:10.1007/s10113-009-0103-y
- 897 Castellanos EJ, Tucker C, Eakin H, Morales H, Barrera JF, Diaz R (2013) Assessing the adaptation
- 898 strategies of farmers facing multiple stressors: Lessons from the Coffee and Global Changes
- 899 project in Mesoamerica *Environmental Science & Policy* 26:19-28
- 900 doi:10.1016/j.envsci.2012.07.003
- 901 Castex V, Moran Tejada E, Beniston M (2015) Water availability, use and governance in the wine
- 902 producing region of Mendoza, Argentina *Environmental Science & Policy* 48:1-8
- 903 doi:10.1016/j.envsci.2014.12.008
- 904 Chandra A, Gaganis P (2015) Deconstructing vulnerability and adaptation in a coastal river basin
- 905 ecosystem: a participatory analysis of flood risk in Nadi, Fiji Islands *Climate and*
- 906 *Development* doi:10.1080/17565529.2015.1016884
- 907 Chuku CA, Okoye C (2009) Increasing resilience and reducing vulnerability in sub-Saharan African
- 908 agriculture: Strategies for risk coping and management *African Journal of Agricultural*
- 909 *Research* 4:1524-1535
- 910 Connolly-Boutin L, Smit B (2015) Climate change, food security, and livelihoods in sub-Saharan
- 911 Africa *Regional Environmental Change* doi:10.1007/s10113-015-0761-x
- 912 Coulibaly JY, Gbetibouo GA, Kundhlande G, Sileshi GW, Beedy TL (2015) Responding to Crop
- 913 Failure: Understanding Farmers' Coping Strategies in Southern Malawi *Sustainability*
- 914 7:1620-1636 doi:10.3390/su7021620
- 915 Drimie S, Gillespie S (2010) Adaptation to climate change in Southern Africa: factoring in AIDS
- 916 *Environmental Science & Policy* 13:778-784 doi:10.1016/j.envsci.2010.07.003
- 917 Elrick-Barr CE, Smith TF, Thomsen DC, Preston BL (2015) Perceptions of Risk among Households
- 918 in Two Australian Coastal Communities *Geographical Research* 53:145-159
- 919 doi:10.1111/1745-5871.12106
- 920 Eriksen S et al. (2011) When not every response to climate change is a good one: Identifying
- 921 principles for sustainable adaptation *Climate and Development* 3:7-20
- 922 doi:10.3763/cdev.2010.0060
- 923 Eriksen S, Lind J (2009) Adaptation as a Political Process: Adjusting to Drought and Conflict in
- 924 Kenya's Drylands *Environmental Management* 43:817-835 doi:10.1007/s00267-008-9189-0
- 925 Eriksen S, Silva JA (2009) The vulnerability context of a savanna area in Mozambique: household
- 926 drought coping strategies and responses to economic change *Environmental Science &*
- 927 *Policy* 12:33-52 doi:10.1016/j.envsci.2008.10.007
- 928 Esham M, Garforth C (2013) Agricultural adaptation to climate change: insights from a farming
- 929 community in Sri Lanka *Mitigation and Adaptation Strategies for Global Change* 18:535-
- 930 549 doi:10.1007/s11027-012-9374-6

- 931 Fazey I, Pettoirelli N, Kenter J, Wagatora D, Schuett D (2011) Maladaptive trajectories of change in
 932 Makira, Solomon Islands Global Environmental Change-Human and Policy Dimensions
 933 21:1275-1289 doi:10.1016/j.gloenvcha.2011.07.006
- 934 Feola G (2013) What (science for) adaptation to climate change in Colombian agriculture? A
 935 commentary on "A way forward on adaptation to climate change in Colombian agriculture:
 936 Perspectives towards 2050" by J. Ramirez-Villegas, M. Salazar, A. Jarvis, C. E. Navarro-
 937 Valcines Climatic Change 119:565-574 doi:10.1007/s10584-013-0731-6
- 938 Feola G, Agudelo Vanegas LA, Contesse Bamón BP (2014) Colombian agriculture under multiple
 939 exposures: a review and research agenda Climate and Development
 940 doi:10.1080/17565529.2014.934776
- 941 Ford JD, Gough WA, Laidler GJ, MacDonald J, Irngaut C, Qrunnut K (2009) Sea ice, climate
 942 change, and community vulnerability in northern Foxe Basin, Canada Climate Research
 943 38:137-154 doi:10.3354/cr00777
- 944 Ford JD, McDowell G, Jones J (2014) The state of climate change adaptation in the Arctic
 945 Environmental Research Letters 9 doi:10.1088/1748-9326/9/10/104005
- 946 Fujisawa M, Kobayashi K (2013) Shifting from apple to peach farming in Kazuno, northern Japan:
 947 perceptions of and responses to climatic and non-climatic impacts Regional Environmental
 948 Change 13:1211-1222 doi:10.1007/s10113-013-0434-6
- 949 Fujisawa M, Kobayashi K, Johnston P, New M (2015) What Drives Farmers to Make Top-Down or
 950 Bottom-Up Adaptation to Climate Change and Fluctuations? A Comparative Study on 3
 951 Cases of Apple Farming in Japan and South Africa Plos One 10
 952 doi:10.1371/journal.pone.0120563
- 953 Gabrielsson S, Ramasar V (2013) Widows: agents of change in a climate of water uncertainty
 954 Journal of Cleaner Production 60:34-42 doi:10.1016/j.jclepro.2012.01.034
- 955 Githinji V, Crane TA (2014) Compound Vulnerabilities: The Intersection of Climate Variability and
 956 HIV/AIDS in Northwestern Tanzania Weather Climate and Society 6:9-21
 957 doi:10.1175/wcas-d-12-00052.1
- 958 Hadarits M, Smit B, Diaz H (2010) Adaptation in viticulture: A case study of producers in the
 959 Maule Region of Chile Journal of Wine Research 21:167-178
 960 doi:10.1080/09571264.2010.530109
- 961 Hageback J, Sundberg J, Ostwald M, Chen D, Yun X, Knutsson P (2005) Climate variability and
 962 land-use change in Danangou watershed, China - Examples of small-scale farmers'
 963 adaptation Climatic Change 72:189-212 doi:10.1007/s10584-005-5384-7
- 964 Harvey CA et al. (2014) Extreme vulnerability of smallholder farmers to agricultural risks and
 965 climate change in Madagascar Philosophical Transactions of the Royal Society B-Biological
 966 Sciences 369 doi:10.1098/rstb.2013.0089
- 967 Head L, Atchison J, Gates A, Muir P (2011) A Fine-Grained Study of the Experience of Drought,
 968 Risk and Climate Change Among Australian Wheat Farming Households Annals of the
 969 Association of American Geographers 101:1089-1108 doi:10.1080/00045608.2011.579533
- 970 Hjerpe M, Glaas E (2012) Evolving local climate adaptation strategies: incorporating influences of
 971 socio-economic stress Mitigation and Adaptation Strategies for Global Change 17:471-486
 972 doi:10.1007/s11027-011-9337-3
- 973 Hopkins D (2015) Applying a Comprehensive Contextual Climate Change Vulnerability
 974 Framework to New Zealand's Tourism Industry Ambio 44:110-120 doi:10.1007/s13280-014-
 975 0525-8
- 976 Ingxay P, Yokoyama S, Hirota I (2015) Livelihood factors and household strategies for an
 977 unexpected climate event in upland northern Laos Journal of Mountain Science 12:483-500
 978 doi:10.1007/s11629-013-2879-y
- 979 Jeffers JM (2013) Double exposures and decision making: adaptation policy and planning in
 980 Ireland's coastal cities during a boom-bust cycle Environment and Planning A 45:1436-1454
 981 doi:10.1068/a45386
- 982 Keskinen M, Chinvano S, Kummu M, Nuorteva P, Snidvongs A, Varis O, Västilä K (2010)

- 983 Climate change and water resources in the lower Mekong River Basin: Putting adaptation
984 into the context *Journal of Water and Climate Change* 1:103-117 doi:10.2166/wcc.2010.009
- 985 Keskitalo ECH (2009) Governance in vulnerability assessment: the role of globalising decision-
986 making networks in determining local vulnerability and adaptive capacity *Mitigation and*
987 *Adaptation Strategies for Global Change* 14:185-201 doi:10.1007/s11027-008-9159-0
- 988 Knox J, Morris J, Hess T (2010) Identifying future risks to UK agricultural crop production Putting
989 climate change in context *Outlook on Agriculture* 39:249-256
- 990 Lankester A (2012) Self-perceived Roles in Life and Achieving Sustainability on Family Farms in
991 North-eastern Australia *Australian Geographer* 43:233-251
992 doi:10.1080/00049182.2012.706202
- 993 Laube W, Schraven B, Awo M (2012) Smallholder adaptation to climate change: dynamics and
994 limits in Northern Ghana *Climatic Change* 111:753-774 doi:10.1007/s10584-011-0199-1
- 995 Lei Y, Wang Ja, Yue Y, Yin Y, Sheng Z (2014) How adjustments in land use patterns contribute to
996 drought risk adaptation in a changing climate-A case study in China *Land Use Policy*
997 36:577-584 doi:10.1016/j.landusepol.2013.10.004
- 998 Leichenko R, O'Brien K, Solecki W (2010) Climate Change and the Global Financial Crisis: A Case
999 of Double Exposure *Annals of the Association of American Geographers* 100:963-972
1000 doi:10.1080/00045608.2010.497340
- 1001 Lereboullet A-L, Beltrando G, Bardsley DK, Rouvellac E (2014) The viticultural system and
1002 climate change: coping with long-term trends in temperature and rainfall in Roussillon,
1003 France *Regional Environmental Change* 14:1951-1966 doi:10.1007/s10113-013-0446-2
- 1004 Lioubimtseva E, Henebry GM (2009) Climate and environmental change in arid Central Asia:
1005 Impacts, vulnerability, and adaptations *Journal of Arid Environments* 73:963-977
1006 doi:10.1016/j.jaridenv.2009.04.022
- 1007 Liu C, Golding D, Gong G (2008) Farmers' coping response to the low flows in the lower Yellow
1008 River: A case study of temporal dimensions of vulnerability *Global Environmental Change-*
1009 *Human and Policy Dimensions* 18:543-553 doi:10.1016/j.gloenvcha.2008.09.002
- 1010 López-i-Gelats F, Contreras Paco JL, Huilcas Huayra R, Siguas Robles OD, Quispe Peña EC,
1011 Bartolomé Filella J (2015) Adaptation Strategies of Andean Pastoralist Households to Both
1012 Climate and Non-Climate Changes *Human Ecology* doi:10.1007/s10745-015-9731-7
- 1013 Lopez-Marrero T, Yarnal B (2010) Putting adaptive capacity into the context of people's lives: a
1014 case study of two flood-prone communities in Puerto Rico *Natural Hazards* 52:277-297
1015 doi:10.1007/s11069-009-9370-7
- 1016 Lung T, Dosio A, Becker W, Lavalle C, Bouwer LM (2013) Assessing the influence of climate
1017 model uncertainty on EU-wide climate change impact indicators *Climatic Change* 120:211-
1018 227 doi:10.1007/s10584-013-0825-1
- 1019 Lung T, Lavalle C, Hiederer R, Dosio A, Bouwer LM (2013) A multi-hazard regional level impact
1020 assessment for Europe combining indicators of climatic and non-climatic change *Global*
1021 *Environmental Change-Human and Policy Dimensions* 23:522-536
1022 doi:10.1016/j.gloenvcha.2012.11.009
- 1023 Mandryk M, Reidsma P, van Ittersum MK (2012) Scenarios of long-term farm structural change for
1024 application in climate change impact assessment *Landscape Ecology* 27:509-527
1025 doi:10.1007/s10980-012-9714-7
- 1026 Mapfumo P, Adjei-Nsiah S, Mtambanengwe F, Chikowo R, Giller KE (2013) Participatory action
1027 research (PAR) as an entry point for supporting climate change adaptation by smallholder
1028 farmers in Africa *Environmental Development* 5:6-22 doi:10.1016/j.envdev.2012.11.001
- 1029 Mason M, Zeitoun M, Sheikh RE (2011) Conflict and social vulnerability to climate change:
1030 Lessons from Gaza *Climate and Development* 3:285-297
1031 doi:10.1080/17565529.2011.618386
- 1032 McCubbin S, Smit B, Pearce T (2015) Where does climate fit? Vulnerability to climate change in
1033 the context of multiple stressors in Funafuti, Tuvalu *Global Environmental Change-Human*
1034 *and Policy Dimensions* 30:43-55 doi:10.1016/j.gloenvcha.2014.10.007

- 1035 McDowell JZ, Hess JJ (2012) Accessing adaptation: Multiple stressors on livelihoods in the
 1036 Bolivian highlands under a changing climate *Global Environmental Change-Human and*
 1037 *Policy Dimensions* 22:342-352 doi:10.1016/j.gloenvcha.2011.11.002
- 1038 McKune SL, Silva JA (2013) Pastoralists under Pressure: Double Exposure to Economic and
 1039 Environmental Change in Niger *Journal of Development Studies* 49:1711-1727
 1040 doi:10.1080/00220388.2013.822067
- 1041 McNeeley SM, Shulski MD (2011) Anatomy of a closing window: Vulnerability to changing
 1042 seasonality in Interior Alaska *Global Environmental Change-Human and Policy Dimensions*
 1043 21:464-473 doi:10.1016/j.gloenvcha.2011.02.003
- 1044 Mertz O et al. (2010) Climate Factors Play a Limited Role for Past Adaptation Strategies in West
 1045 Africa *Ecology and Society* 15
- 1046 Metcalf SJ, van Putten EI, Frusher SD, Tull M, Marshall N (2014) Adaptation options for marine
 1047 industries and coastal communities using community structure and dynamics *Sustainability*
 1048 *Science* 9:247-261 doi:10.1007/s11625-013-0239-z
- 1049 Moerlein KJ, Carothers C (2012) Total Environment of Change: Impacts of Climate Change and
 1050 Social Transitions on Subsistence Fisheries in Northwest Alaska *Ecology and Society* 17
 1051 doi:10.5751/es-04543-170110
- 1052 Morton JF (2007) The impact of climate change on smallholder and subsistence agriculture
 1053 *Proceedings of the National Academy of Sciences of the United States of America*
 1054 104:19680-19685 doi:10.1073/pnas.0701855104
- 1055 Mubaya CP, Njuki J, Mutsvangwa EP, Mugabe FT, Nanjad D (2012) Climate variability and change
 1056 or multiple stressors? Farmer perceptions regarding threats to livelihoods in Zimbabwe and
 1057 Zambia *Journal of Environmental Management* 102:9-17
 1058 doi:10.1016/j.jenvman.2012.02.005
- 1059 Mustelin J, Klein RG, Assaid B, Sitari T, Khamis M, Mzee A, Haji T (2010) Understanding current
 1060 and future vulnerability in coastal settings: community perceptions and preferences for
 1061 adaptation in Zanzibar, Tanzania *Population and Environment* 31:371-398
 1062 doi:10.1007/s11111-010-0107-z
- 1063 Nicholls RJ, Wong PP, Burkett V, Woodroffe CD, Hay J (2008) Climate change and coastal
 1064 vulnerability assessment: scenarios for integrated assessment *Sustainability Science* 3:89-
 1065 102 doi:10.1007/s11625-008-0050-4
- 1066 Nunn PD (2013) The end of the Pacific? Effects of sea level rise on Pacific Island livelihoods
 1067 *Singapore Journal of Tropical Geography* 34:143-171 doi:10.1111/sjtg.12021
- 1068 Nuorteva P, Keskinen M, Varis O (2010) Water, livelihoods and climate change adaptation in the
 1069 Tonle Sap Lake area, Cambodia: learning from the past to understand the future *Journal of*
 1070 *Water and Climate Change* 1:87-101 doi:10.2166/wcc.2010.010
- 1071 Nussbaumer S, Schaub Y, Huggel C, Walz A (2014) Risk estimation for future glacier lake outburst
 1072 floods based on local land-use changes *Natural Hazards and Earth System Sciences*
 1073 14:1611-1624 doi:10.5194/nhess-14-1611-2014
- 1074 Nyantakyi-Frimpong H, Bezner-Kerr R (2015) The relative importance of climate change in the
 1075 context of multiple stressors in semi-arid Ghana *Global Environmental Change* 32:40-56
 1076 doi:10.1016/j.gloenvcha.2015.03.003
- 1077 O'Brien K, Leichenko R (2000) Double exposure: assessing the impacts of climate change within
 1078 the context of economic globalization *Global Environmental Change-Human and Policy*
 1079 *Dimensions* 10:221-232 doi:10.1016/s0959-3780(00)00021-2
- 1080 O'Brien K et al. (2004) Mapping vulnerability to multiple stressors: climate change and
 1081 globalization in India *Global Environmental Change-Human and Policy Dimensions*
 1082 14:303-313 doi:10.1016/j.gloenvcha.2004.01.001
- 1083 O'Brien K, Quinlan T, Ziervogel G (2009) Vulnerability interventions in the context of multiple
 1084 stressors: lessons from the Southern Africa Vulnerability Initiative (SAVI) *Environmental*
 1085 *Science & Policy* 12:23-32 doi:10.1016/j.envsci.2008.10.008
- 1086 Orr CJ, Williams KC, Laurent KL, Friedman KB, Krantzberg G, Scavia D, Creed IF (2015) Trying

- 1087 hard to adapt to a chaotic world: How complex challenges overwhelmed best intentions
 1088 Journal of Great Lakes Research 41:139-149 doi:10.1016/j.jglr.2014.12.003
- 1089 Paavola J (2008) Livelihoods, vulnerability and adaptation to climate change in Morogoro,
 1090 Tanzania Environmental Science & Policy 11:642-654 doi:10.1016/j.envsci.2008.06.002
- 1091 Pearce T, Ford JD, Caron A, Kudlak BP (2012) Climate change adaptation planning in remote,
 1092 resource-dependent communities: An Arctic example Regional Environmental Change
 1093 12:825-837 doi:10.1007/s10113-012-0297-2
- 1094 Pearce T, Smit B, Duerden F, Ford JD, Goose A, Kataoyak F (2010) Inuit vulnerability and adaptive
 1095 capacity to climate change in Ulukhaktok, Northwest Territories, Canada Polar Record
 1096 46:157-177 doi:10.1017/s0032247409008602
- 1097 Perry RI, Ommer RE, Barange M, Werner F (2010) The challenge of adapting marine social-
 1098 ecological systems to the additional stress of climate change Current Opinion in
 1099 Environmental Sustainability 2:356-363 doi:10.1016/j.cosust.2010.10.004
- 1100 Petheram L, Zander KK, Campbell BM, High C, Stacey N (2010) 'Strange changes': Indigenous
 1101 perspectives of climate change and adaptation in NE Arnhem Land (Australia) Global
 1102 Environmental Change-Human and Policy Dimensions 20:681-692
 1103 doi:10.1016/j.gloenvcha.2010.05.002
- 1104 Pricope NG, Husak G, Lopez-Carr D, Funk C, Michaelsen J (2013) The climate-population nexus
 1105 in the East African Horn: Emerging degradation trends in rangeland and pastoral livelihood
 1106 zones Global Environmental Change-Human and Policy Dimensions 23:1525-1541
 1107 doi:10.1016/j.gloenvcha.2013.10.002
- 1108 Prno J, Bradshaw B, Wandel J, Pearce T, Smit B, Tozer L (2011) Community vulnerability to
 1109 climate change in the context of other exposure-sensitivities in Kugluktuk, Nunavut Polar
 1110 Research 30 doi:10.3402/polar.v30i0.7363
- 1111 Quinn CH, Ziervogel G, Taylor A, Takama T, Thomalla F (2011) Coping with Multiple Stresses in
 1112 Rural South Africa Ecology and Society 16 doi:10.5751/es-04216-160302
- 1113 Rattenbury K, Kielland K, Finstad G, Schneider W (2009) A reindeer herder's perspective on
 1114 caribou, weather and socio-economic change on the Seward Peninsula, Alaska Polar
 1115 Research 28:71-88 doi:10.1111/j.1751-8369.2009.00102.x
- 1116 Reenberg A, Maman I, Oksen P (2013) Twenty years of land use and livelihood changes in SE-
 1117 Niger: Obsolete and short-sighted adaptation to climatic and demographic pressures?
 1118 Journal of Arid Environments 94:47-58 doi:10.1016/j.jaridenv.2013.03.002
- 1119 Reenberg A, Rasmussen LV, Nielsen JO (2012) Causal relations and land use transformation in the
 1120 Sahel: conceptual lenses for processes, temporal totality and inertia Geografisk Tidsskrift-
 1121 Danish Journal of Geography 112:159-173 doi:10.1080/00167223.2012.741888
- 1122 Reid P, Vogel C (2006) Living and responding to multiple stressors in South Africa-Glimpses from
 1123 KwaZulu-Natal Global Environmental Change 16:195-206
 1124 doi:10.1016/j.gloenvcha.2006.01.003
- 1125 Reidsma P, Wolf J, Kanellopoulos A, Schaap BF, Mandryk M, Verhagen J, Van Ittersum MK (2015)
 1126 Climate change impact and adaptation research requires integrated assessment and farming
 1127 systems analysis: A case study in the Netherlands Environmental Research Letters 10
 1128 doi:10.1088/1748-9326/10/4/045004
- 1129 Shackleton SE, Shackleton CM (2012) Linking poverty, HIV/AIDS and climate change to human
 1130 and ecosystem vulnerability in southern Africa: consequences for livelihoods and
 1131 sustainable ecosystem management International Journal of Sustainable Development and
 1132 World Ecology 19:275-286 doi:10.1080/13504509.2011.641039
- 1133 Shameem MIM, Momtaz S, Rauscher R (2014) Vulnerability of rural livelihoods to multiple
 1134 stressors: A case study from the southwest coastal region of Bangladesh Ocean & Coastal
 1135 Management 102:79-87 doi:10.1016/j.ocecoaman.2014.09.002
- 1136 Silva JA, Eriksen S, Ombe ZA (2010) Double exposure in Mozambique's Limpopo River Basin
 1137 Geographical Journal 176:6-24 doi:10.1111/j.1475-4959.2009.00343.x
- 1138 Smit B, McNabb D, Smithers J (1996) Agricultural adaptation to climatic variation Climatic

- 1139 Change 33:7-29 doi:10.1007/bf00140511
- 1140 Smit B, Skinner MW (2002) Adaptation options in agriculture to climate change: A typology
1141 Mitigation and Adaptation Strategies for Global Change 7:85-114
1142 doi:10.1023/a:1015862228270
- 1143 Srinivasan V, Thomas BK, Jamwal P, Lele S (2013) Climate vulnerability and adaptation of water
1144 provisioning in developing countries: approaches to disciplinary and research-practice
1145 integration *Current Opinion in Environmental Sustainability* 5:378-383
1146 doi:10.1016/j.cosust.2013.07.011
- 1147 Suckall N, Tompkins E, Stringer L (2014) Identifying trade-offs between adaptation, mitigation and
1148 development in community responses to climate and socio-economic stresses: Evidence
1149 from Zanzibar, Tanzania *Applied Geography* 46:111-121 doi:10.1016/j.apgeog.2013.11.005
- 1150 Sugden F, Maskey N, Clement F, Ramesh V, Philip A, Rai A (2014) Agrarian stress and climate
1151 change in the Eastern Gangetic Plains: Gendered vulnerability in a stratified social
1152 formation *Global Environmental Change-Human and Policy Dimensions* 29:258-269
1153 doi:10.1016/j.gloenvcha.2014.10.008
- 1154 Torres R, Azocar G, Rojas J, Montecinos A, Paredes P (2015) Vulnerability and resistance to
1155 neoliberal environmental changes: An assessment of agriculture and forestry in the Biobio
1156 region of Chile (1974-2014) *Geoforum* 60:107-122 doi:10.1016/j.geoforum.2014.12.013
- 1157 Trotman A, Gordon RM, Hutchinson SD, Singh R, McRae-Smith D (2009) Policy responses to
1158 GEC impacts on food availability and affordability in the Caribbean community
1159 *Environmental Science & Policy* 12:529-541 doi:10.1016/j.envsci.2009.02.001
- 1160 Tschakert P (2007) Views from the vulnerable: Understanding climatic and other stressors in the
1161 Sahel *Global Environmental Change-Human and Policy Dimensions* 17:381-396
1162 doi:10.1016/j.gloenvcha.2006.11.008
- 1163 Tucker C (2000) Floods in Canada: An emergency preparedness Canada (EPC) perspective
1164 *Environments* 28:75-87
- 1165 Tucker CM, Eakin H, Castellanos EJ (2010) Perceptions of risk and adaptation: Coffee producers,
1166 market shocks, and extreme weather in Central America and Mexico *Global Environmental*
1167 *Change-Human and Policy Dimensions* 20:23-32 doi:10.1016/j.gloenvcha.2009.07.006
- 1168 Tucker J, Daoud M, Oates N, Few R, Conway D, Mtisi S, Matheson S (2014) Social vulnerability in
1169 three high-poverty climate change hot spots: What does the climate change literature tell us?
1170 *Regional Environmental Change* doi:10.1007/s10113-014-0741-6
- 1171 Tyler NJC et al. (2007) Saami reindeer pastoralism under climate change: Applying a generalized
1172 framework for vulnerability studies to a sub-arctic social-ecological system *Global*
1173 *Environmental Change* 17:191-206 doi:10.1016/j.gloenvcha.2006.06.001
- 1174 van Putten I, Metcalf S, Frusher S, Marshall N, Tull M (2014) Fishing for the impacts of climate
1175 change in the marine sector: a case study *International Journal of Climate Change Strategies*
1176 *and Management* 6:421-441 doi:10.1108/ijccsm-01-2013-0002
- 1177 Wang Y, Wang J, Li S, Qin D (2014) Vulnerability of the Tibetan Pastoral Systems to Climate and
1178 *Global Change Ecology and Society* 19 doi:10.5751/es-06803-190408
- 1179 Warner BP, Kuzdas C, Yglesias MG, Childers DL (2015) Limits to adaptation to interacting global
1180 change risks among smallholder rice farmers in Northwest Costa Rica *Global*
1181 *Environmental Change-Human and Policy Dimensions* 30:101-112
1182 doi:10.1016/j.gloenvcha.2014.11.002
- 1183 Vasquez-Leon M (2009) Hispanic Farmers and Farmworkers: Social Networks, Institutional
1184 Exclusion, and Climate Vulnerability in Southeastern Arizona *American Anthropologist*
1185 111:289-301 doi:10.1111/j.1548-1433.2009.01133.x
- 1186 Westerhoff L, Smit B (2009) The rains are disappointing us: dynamic vulnerability and adaptation
1187 to multiple stressors in the Afram Plains, Ghana *Mitigation and Adaptation Strategies for*
1188 *Global Change* 14:317-337 doi:10.1007/s11027-008-9166-1
- 1189 Wilbanks TJ, Kates RW (2010) Beyond Adapting to Climate Change: Embedding Adaptation in
1190 Responses to Multiple Threats and Stresses *Annals of the Association of American*

1191 Geographers 100:719-728 doi:10.1080/00045608.2010.500200
 1192 Wilder M, Scott CA, Pineda Pablos N, Varady RG, Garfin GM, McEvoy J (2010) Adapting Across
 1193 Boundaries: Climate Change, Social Learning, and Resilience in the U.S.-Mexico Border
 1194 Region *Annals of the Association of American Geographers* 100:917-928
 1195 doi:10.1080/00045608.2010.500235
 1196 Wilk J, Andersson L, Warburton M (2013) Adaptation to climate change and other stressors among
 1197 commercial and small-scale South African farmers *Regional Environmental Change* 13:273-
 1198 286 doi:10.1007/s10113-012-0323-4
 1199 Wilk J, Hjerpe M, Yang W, Fan H (2014) Farm-scale adaptation under extreme climate and rapid
 1200 economic transition *Environment, Development and Sustainability* doi:10.1007/s10668-014-
 1201 9549-2
 1202 Vincent K, Cull T, Chanika D, Hamazakaza P, Joubert A, Macome E, Mutonhodza-Davies C (2013)
 1203 Farmers' responses to climate variability and change in southern Africa - is it coping or
 1204 adaptation? *Climate and Development* 5:194-205 doi:10.1080/17565529.2013.821052
 1205 Xu J, Grumbine RE (2014) Building ecosystem resilience for climate change adaptation in the
 1206 Asian highlands *Wiley Interdisciplinary Reviews-Climate Change* 5:709-718
 1207 doi:10.1002/wcc.302
 1208 Yaro JA (2013) The perception of and adaptation to climate variability/change in Ghana by small-
 1209 scale and commercial farmers *Regional Environmental Change* 13:1259–1272
 1210 Yumul GP, Jr., Dimalanta CB, Servando NT, Cruz NA (2013) Abnormal weather events in 2009,
 1211 increased precipitation and disastrous impacts in the Philippines *Climatic Change* 118:715-
 1212 727 doi:10.1007/s10584-012-0661-8
 1213 Zheng Y, Byg A, Thorsen BJ, Strange N (2014) A Temporal Dimension of Household Vulnerability
 1214 in Three Rural Communities in Lijiang, China *Human Ecology* 42:283-295
 1215 doi:10.1007/s10745-013-9633-5
 1216 Ziervogel G, Bharwani S, Downing TE (2006) Adapting to climate variability: Pumpkins, people
 1217 and policy *Natural Resources Forum* 30:294-305 doi:10.1111/j.1477-8947.2006.00121.x
 1218