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1 **Title**

2 Is the governance of the Thau coastal lagoon ready to face climate change impacts?

3 **Authors**

I. La Jeunesse^{1,2}, C. Cirelli¹, H. Sellami³, D. Aubin⁴, R. Deidda^{5,6}, N. Baghdadi⁷

4 **Author affiliations**

5 ¹ Université François Rabelais de Tours, UMR CNRS 7324 Citeres, 33, allée Ferdinand de Lesseps,
6 B.P. 60449, 37204 Tours cedex 3, France

7 ² University of Angers, UMR CNRS 6554 LETG – Angers, 2 bd Lavoisier, 49045 Angers, France

8 ³ Université catholique de Louvain, Earth and Life Institute, Croix du sud 2, bte 1, B-1348 Louvain-la-
9 Neuve, Belgium

10 ⁴ Université catholique de Louvain, Institut de sciences politiques Louvain-Europe, Place Montesquieu
11 1, b^{te} L2.08.07, B-1348 Louvain-la-Neuve, Belgium

12 ⁵ University of Cagliari, Department of Civil and Environmental Engineering and Architecture, Via
13 Marengo 2, 09123 Cagliari, Italy

14 ⁶ CINFAI, Consorzio Interuniversitario Nazionale per la Fisica delle Atmosfere e delle Idrosfere,
15 Tolentino, Italy

16 ⁷ IRSTEA, UMR TETIS, 500 rue François Breton, 34093 Montpellier cedex 5, France

17 **Corresponding author**

18 Isabelle La Jeunesse, Université François Rabelais de Tours, UMR CNRS 7324 Citeres, 33, allée
19 Ferdinand de Lesseps, B.P. 60449, 37204 Tours cedex 3, France, isabelle.lajeunesse@univ-tours.fr

20 **Abstract**

21 The present paper provides a reflection on threats to integrated management of the Thau coastal
22 lagoon due to climate change and the multi-scalar water scarcity adaptation strategy. This study
23 proposes first to depict the Thau water governance assessed through a water use and social network
24 analysis and its capacity to manage water quality. Next, this paper provides a downscaled study on
25 the climate change impacts on the hydrological budget of the entire Thau catchment in 2041-2070
26 compared with the 1971-2000 reference period, a methodology developed during the CLIMB EU

27 research program. Following local climate change impacts, the importation of a new water resource to
28 secure water uses is presented in regards to the capacity of local water governance to maintain
29 coherence between integrated land planning and integrated water management planning based on
30 water quality issues of the Thau coastal lagoon. The study underlines that although the water uses are
31 currently secured thanks to the regional transfer of water, they are not coherent with local water
32 management and create new vulnerabilities in the context of climate change. Moreover, the regional
33 decision to end financial support for the more efficient, existing network for the water quality survey of
34 regional coastal lagoons breaks up the local water governance. This paper demonstrates why keeping
35 this network would have been absolutely necessary for encouraging a governance capable of
36 proposing sustainable solutions to water quality challenges induced by climate change.

37 **Keywords:** climate change, integrated coastal management, hydrology, water governance

38 **Highlights**

- 39 • Climate change will increase temperature and decrease runoff in the Thau catchment
- 40 • Climate change challenges for local water uses are not perceived by local stakeholders
- 41 • Regional water management provides security for domestic use including tourism, and irrigation
- 42 • Regional water management increases the vulnerability of local water governance
- 43 • CLIMB EU FP7 project, CLIWASEC cluster, multidisciplinary analyses

44 **Introduction**

45 According to the IPCC climate model projections, Mediterranean countries are at high risk for
46 pronounced susceptibility to changes in temperature in the hydrological budget and in the occurrence
47 and magnitude of extreme conditions (IPCC, 2007; Giorgi and Lionello, 2008). Moreover, the increase
48 in temperature of marine waters and its interaction with acidification may induce an amplification of
49 eutrophication and hypoxia (Bijma et al., 2013).

50 It can be foreseen that the changes in the hydrologic cycle will give rise to an increasing potential for
51 conflicts (Ludwig et al., 2011), or at least rivalries (Bressers and Kuks, 2004; Aubin, 2008; La
52 Jeunesse et al., 2013), and possible tensions among the political and economic actors. To provide
53 expertise and adaptation strategies, multidisciplinary research is needed to tackle the multi-facet
54 complexity of climate change impacts on water resources (Quevauviller et al., 2012) a fortiori in the
55 Mediterranean (Santos et al., 2014). In this context, the cluster of three EU projects CLIWASEC is

56 tackling the 'climate change – water – security' nexus. One of those, the CLIMB project, is focusing on
57 inter-linkages and interdisciplinary analyses around the quantification of uncertainties in climate
58 change impact and risk assessment (Ludwig et al., 2010).

59 Several empirical and simulation studies support the idea of increased eutrophication with climate
60 change which contradict the expectations of reductions in nutrient loading from catchments in drier
61 climates and greater stability of the water column in warmer climates (IPCC, 2007). Because of the
62 already high anthropogenic pressures coming from both coastal and continental areas, transitional
63 waters and a fortiori coastal lagoons, as semi-enclosed ponds, are the ecosystems particularly
64 exposed to the impacts of climate change.

65 Following this list of impacts, effective adaptation measures require multi-disciplinary preparation and
66 efficient water governance (Ostrom, 1990). *“Governance refers to all processes of governing [...], it
67 focuses not only on the State and its institutions but also the creation of rule and order in social
68 practices”* (Bevir, 2013). Thus, governance is a mix of procedures (hierarchical, networked, or market-
69 oriented) which involves public and private stakeholders in the management of an issue of public
70 interest. The focus here is on the local networks of public and private water users and managers and
71 the ways these stakeholders manage water-related issues and problems. In particular, transitional
72 waters at the confluence of continental and marine issues are complex ecosystems with important
73 anthropogenic pressures sometimes exacerbated by inappropriate management in diverse chains of
74 cause-effect relationships (Newton et al., 2014).

75 The European Union started to define rules for Integrated Coastal Zone Management (ICZM, Cicin-
76 Sain and Knecht, 1998) first through the Water Framework Directive (WFD), which covers the
77 transitional and coastal waters up to 1 nautical mile from the continental baseline. The ICZM has been
78 completed for marine waters by a marine policy initiated in 2008 with its environmental part
79 represented by the Marine Strategy Framework Directive (Borja et al., 2010 ; Elliott, 2013).

80 Nationally, France has a history of using coastal spatial planning instruments with a regulation tool
81 called 'Schéma de Mise en Valeur de la Mer' (SMVM). The key features of this marine spatial planning
82 process was based on the cooperation of multiple partners including a development phase in which
83 elected officials and all stakeholders (sector representatives and experts) are involved, with final
84 approval by State representatives.

85 Thau has been a leader in France for ICZM planning with the first implemented SMVM in 1995
86 (Trouillet et al., 2011). In fact, the benefits of maintaining the water quality of the Thau lagoon have
87 been evident since the ecological crisis of the 1970s, when 100% of the Thau lagoon waters suffered
88 from an anoxic crisis due to eutrophication, which destroyed 100% of the shellfish farming stocks. To
89 implement the WFD in transitional waters along the coastline and as stakeholder involvement in water
90 management planning and public consultation has become mandatory for member states, the
91 Languedoc-Roussillon (LR) region initiated in 2000 a new network to address eutrophication for
92 coastal lagoons under the name Lagoon Monitoring Network (LMN). This network, with steering
93 committee composed of five stakeholders of water and marine production management (the LR
94 region, the water agency of the Rhône-Méditerranée-Corse basin, the DREAL as the state
95 representative for environmental management, the Ceprelmar as the regional institute created in 1981
96 for promoting marine production that drives the LMN, and Ifremer as the partner for scientific research
97 expertise), launched two 6-year contracts. The objectives were to build a eutrophication monitoring
98 program of the lagoons of the LR region to deliver an operational Decision Support System (DSS) to
99 local stakeholders to support their decentralized management of the lagoons.

100 In the meantime, the creation through a bottom-up strategy of SAGE-Thau (Schéma d'Aménagement
101 et de Gestion des Eaux as the Thau River Basin Management Plan), driven by a local public body
102 called the SMTB (Syndicat Mixte du Bassin de Thau), which acts on the behalf of the two largest
103 intercommunalities of the Thau lagoon - CABT (Communauté d'Agglomération du Nord du Bassin de
104 Thau) and CCNBT (Communauté des Communes du Nord du Bassin de Thau), has permitted the
105 development of an integrated management of water quality in the Thau lagoon.

106 In fact, it is now well known worldwide and even locally that a common knowledge base between
107 stakeholders, expert and scientists is requisite for implementing more elaborate forms of participation
108 (Loubier et al., 2005; Rinaudo and Garin, 2005). The water quality restoration of the Thau coastal
109 lagoon is the result of twenty years of several multi-disciplinary investigation programs alternately
110 conducted by scientists and the local public bodies (e.g., OxyThau, EcoThau, PNEC, Omega-Thau,
111 SPICOSA and so forth). DSS tools provided by the synthesis of these programs are currently used by
112 the SMTB to produce indicators of water quality vulnerability (Mongruel et al., 2013). Some DSSs on
113 lagoon water quality are provided, such as the one related to eutrophication, O'GAMELAG, or others
114 related more to microbial contamination such as VigiThau. In parallel, other tools under development

115 propose to model how local territories, such as the Thau coastal lagoon, have promoted endogenous
116 development based on Socio-Technical Information and Communication Arrangements at the scale of
117 inter-municipal authorities to support mediation between heterogeneous actors which drives territorial
118 intelligence (Bertacchini et al., 2013; Maurel et al., 2014, Plant et al., 2014).

119 Furthermore, the Thau coastal lagoon has kept its 'status' as a pilot site for ICZM through its
120 nomination by the DATAR (Délégation interministérielle à l'Aménagement du Territoire et à
121 l'Attractivité Régionale) interministerial delegation as a pilot site for the implementation of community
122 regulations for ICZM strategies. Thus, in April 2013, an Integrated Management Contract (IMC) was
123 signed for the Thau territory for the period 2012-2017. Its main objective was to provide coordination of
124 all the management tools implemented in the territory including the preservation of Thau coastal
125 lagoon water quality as the support of marine production.

126 Therefore, this paper aims to provide a reflection on climate-induced threats to integrated
127 management of the Thau coastal lagoon and the multi-scalar adaptation strategy. It proposes first to
128 depict the Thau water governance assessed through a water use and social network analysis and its
129 capacity to manage water quality. Then, this paper provides a study of the downscaled climate change
130 impacts on the hydrological budget of the entire Thau catchment in 2041-2070 compared with the
131 1971-2000 reference period. Following local climate change impacts, the importation of new waters to
132 secure water uses is presented in regards to the capacity of local water governance to maintain
133 coherence between integrated land planning and integrated water management planning based on the
134 water quality issues of the Thau coastal lagoon.

135 **Material and Methods**

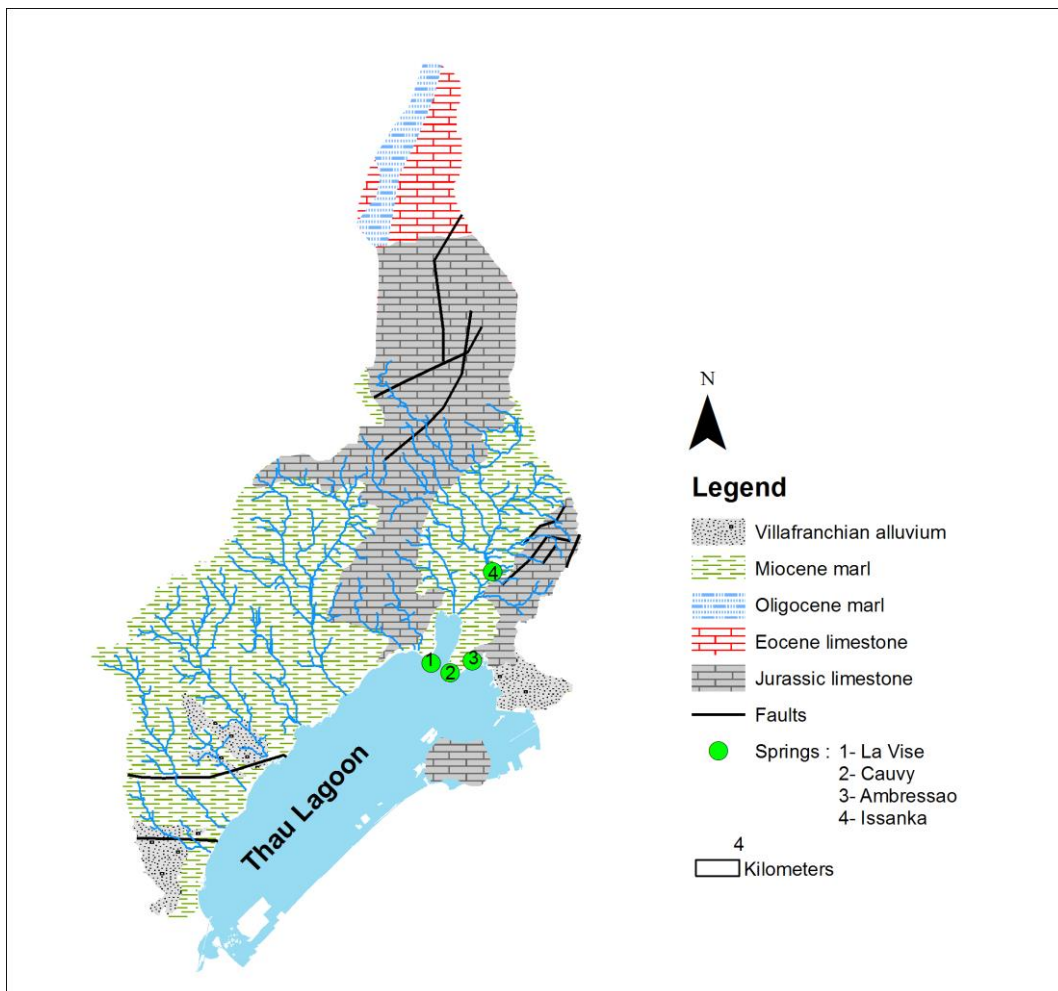
136 **The Thau catchment – coastal lagoon hydrosystem**

137 ***The coastal lagoon***

138 The Thau lagoon is located in the LR region in the Hérault Department in the south of France. It is a
139 75 km² water body 19.5 km long and 4.5 km wide with a mean depth of 4 m and a high variability of
140 salinity. Approximately one fifth of the lagoon's area (1,500 ha) is farmed for shellfish production, with
141 shellfish farming occurring in three zones on the lagoon (Figure 2). It is also used for fishing.

142 The lagoon is in connection with the Thau karstic system which is made of complex karstic networks of
143 Jurassic limestone with several inland and submarine springs (Figure 1). The latter plays an important

144 economical role since it supplies water for fish breeding, for the spa in Balaruc-les-Bains, and most
 145 importantly, for some local drinking water supply (Pinault et al., 2004). Complex interactions between
 146 the lagoon and the karstic system exist. For instance, seawater can occasionally inter the karstic
 147 system through the spring conduits (Figure 1), depending on several factors including the hydraulic
 148 head in the aquifer and in the Sea, rainfall event and water density in the aquifer (Pinault, 2004). This
 149 phenomenon is locally known as *inversac*, and it can last for several weeks.
 150 The frequency of anoxic crises, intensified during the second half of the 20th century (Elbaz-Poulichet
 151 et al., 2004), is a consequence of both eutrophication levels (La Jeunesse and Elliott, 2004) and
 152 particular meteorological conditions (Chapelle et al., 2000). Depending on the severity of the hypoxia,
 153 it can lead to the destruction of shellfish stocks.

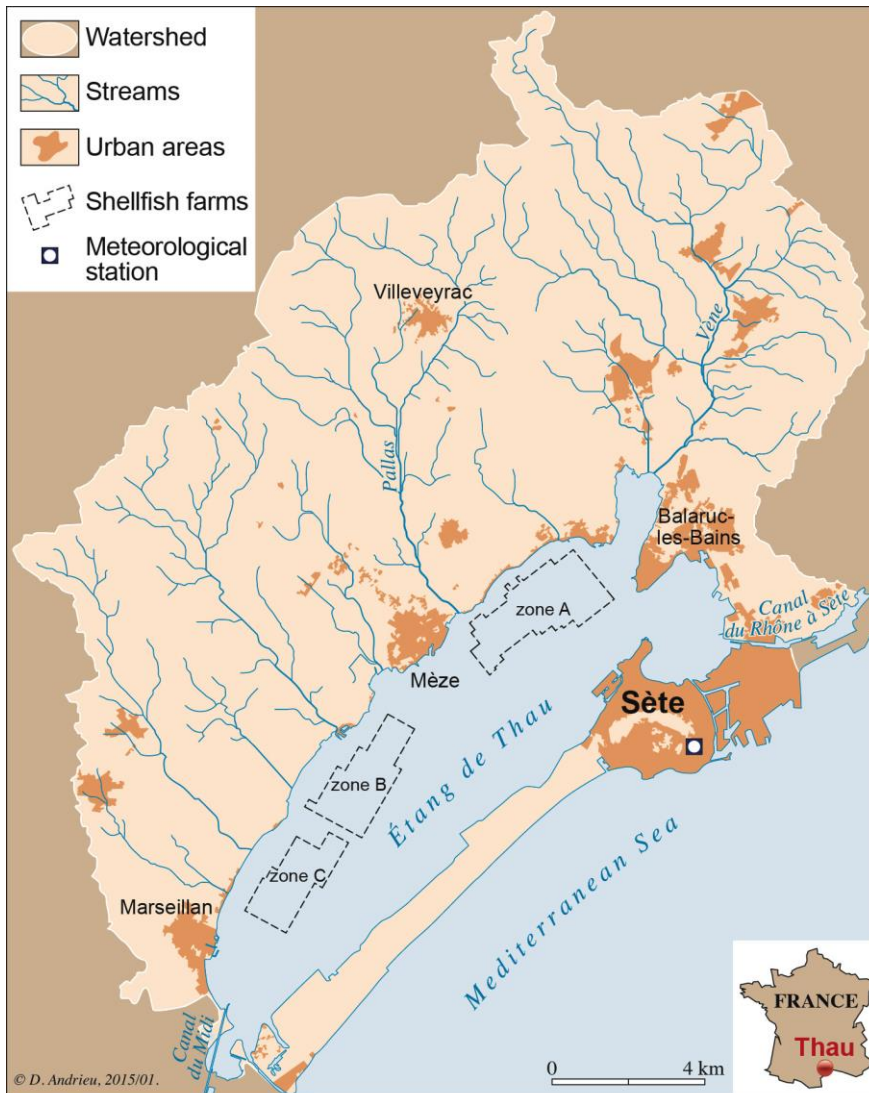


154
 155 **Figure 1: Simplified geological map of the Thau karstic system**

156 ***The catchment area***

157 The Thau catchment covers approximately 280 km² (Figure 2). Almost 70% of the land devoted to
158 agriculture is used for vineyards. Approximately half of the area's permanent population of 115,000
159 inhabitants is located in the city of Sète, situated on the southern shore of the lagoon. The population
160 of the region is continuing to increase, and in summer tourists, mainly linked to the Mediterranean Sea
161 side double the population of the area. A second French spa is located in Balaruc-les-Bains on the
162 Thau coastline.

163 The catchment area is drained by a dozen intermittent small streams that flow directly into the lagoon.
164 The Vène and the Pallas are the two main watersheds of the Thau, and they cover an area of
165 approximately 67 km² and 54 km², respectively, representing approximately 54% of the total surface of
166 the Thau watershed and accounting together between 50% to 80% of total freshwater inputs into the
167 lagoon (Plus et al., 2006; Sellami et al., 2013).



168

169 **Figure 2: Localization of the Thau coastal lagoon and its catchment in the French Mediterranean coast**

170 ***The local climate***

171 The local climatic features were estimated from the historical observations recorded by the Météo-
 172 France meteorological station of Sète from 1970 to 2010 (Figure 2). This station is considered as
 173 representative for the whole catchment. This assumption is justified by the fact that the Thau
 174 catchment is rather small and quite flat; thus, it does not display significant spatial variability except for
 175 some orographic effects, which can be easily accounted for. The analysis of the 40-year time series in
 176 Sète revealed a marked inter-annual variability of the local precipitation climate. Indeed, the annual
 177 precipitation depth varies from 290 to 1000 mm, while the average is approximately 600 mm per year.
 178 Examining the monthly distribution more closely, precipitation displays a marked seasonal variability:
 179 precipitation occurs mainly during autumn and winter with frequent intense storms, whereas a long dry

180 period usually extends from the end of winter to the end of summer, with a minimum in July. The
181 climatic distribution of monthly precipitation has been used to apply the final local-scale bias-correction
182 as described later. The analysis of the temperature time series reveals that the hottest months are July
183 and August and that daily temperature maxima exceeding 35°C are frequently observed, while the
184 coldest months are December and January when daily minimum temperatures can sometimes be
185 lower than -5°C (Sellami et al., 2013).

186 ***The French water management***

187 At the hydrographic district scale, water agencies are responsible for the characterization of water
188 bodies, public consultation, participation of water users in the water management policy, and
189 preparation of the 6-year river basin management plans (called SDAGE) and programs of measures to
190 implement the Water Framework Directive (WFD).

191 At the local level, the decision and implementation of water regulations strictly rely on the departmental
192 prefects, who represent the central government at the administrative level. Then, state management is
193 made through decentralized services: the DREAL (Regional Direction of Environment, Planning and
194 Housing) and the DDTM (Departmental Direction of the Territories and the Sea).

195 At the sub-catchment scale, one of the main water management tools in France is SAGE. It is a
196 planning document that pursues both quantitative and qualitative protection goals for water resources.
197 When SAGE is approved, all decisions concerning water issues in the area must comply with its
198 objectives. This legal status not only concerns the administration but also private individuals. It is
199 developed by local actors (policymakers, users, NGOs, representatives of the state and elected
200 people representing municipalities) together within the Local Water Commission (LWC). LWC has the
201 status of an administrative commission without a legal personality. It organizes and manages the
202 entire process of development, consultation and implementation of SAGE. It is an ideal place for
203 dialogue, debate, advocacy and decision-making.

204 Since the urban planning law (SRU) of 2000, a planning document known as the scheme of territorial
205 coherence, SCoT, has determined at a scale of several municipalities the general guidelines for land
206 planning for the next 10 years. As urban planning and water management have common concerns,
207 SCoT and SAGE require coherent ambitions. On the Thau territory, these two main local public
208 policies instruments are driven by the SMT.

209 ***The regional hydraulic management***

210 The French use of regional Mediterranean water has through the centuries led to important hydraulic
211 techniques for transferring water from regions with water availability to regions with important water
212 needs that are not sufficiently supported. In this situation, the Rhône River represents the major river
213 of the Mediterranean coast and was obviously the coveted river for pumping and transferring between
214 catchments. A national company for managing the water transfer was created in 1955 by Philippe
215 Lamour under the name CNABRL (Compagnie Nationale d'Aménagement Bas-Rhône-Languedoc).
216 The project is for a vast irrigation network (canals and dams) that conducts water from the Rhône
217 River with three departments (Gard, Hérault and Aude), allowing the development of diversified
218 agriculture. A few years after extending hydraulic networks to the coastline of the LR Region, this
219 water was also used for domestic use and thus tourism purposes.

220 CNABRL, currently called BRL, is still the regional partner for water management and for the regional
221 climate plan. The strategic analysis center of BRL presents the water resources and water needs in
222 France at the horizon of 2030 (BRL, 2006, 2012) which includes because of climate change, the need
223 for more irrigation water in the LR Region. Aqua2020 proposed the project Aqua Domitia (Aqua
224 Domitia, 2011) consisting of the extension of the existing Lamour channel to the city of Narbonne near
225 the Spanish border. It has brought untreated water from the Rhône River directly to the Thau
226 catchment since 2012. As the salinity of exploited surges in the Thau catchment has increased rapidly
227 during the last several years, and the current drinking water plants connected to the Hérault catchment
228 need to be updated, a new drinking water treatment plant started to treat water from the Rhône River
229 in February 2012. Since then, local inhabitants have been drinking treated water from the Rhône River
230 mixed with water from closer sources.

231 **Regional downscaled climate change**

232 The climate forcing used in this study was obtained in the context of a preliminary analysis conducted
233 in the framework of the EU-FP7 CLIMB project. The first phase was devoted to the auditing of the
234 outputs of 14 regional climate models (RCMs), which were run for the A1B emission scenario of the
235 AR4 (IPCC, 2007) and were made available through the EU-FP6 ENSEMBLES project. A set of the
236 four best-performing RCMs in reproducing the precipitation and temperature climates are considered
237 (Deidda et al., 2013) while E-OBS products (Haylock et al., 2008) were used as reference. Daily

238 precipitation and the daily minimum/mean/maximum temperature time series in each grid point of the
239 four selected models were first bias-corrected using quantile-quantile transformations to reproduce all
240 the features of E-OBS climatology. Since the RCM grid resolution was approximately 25 km and thus
241 not fully representative for hydrological modelling, the precipitation and temperature fields were further
242 processed with downscaling and interpolation techniques. Specifically, the precipitation fields were
243 downscaled to a 1 km resolution using the Space-Time RAINfall model (STRAIN) described in Deidda
244 (2000), for which performance was tested in several contexts (e.g., Deidda et al., 2004, 2006). To
245 account for the orographic effects, a modulation function was then applied as described in Badas et al.
246 (2006). Temperature fields were instead interpolated at a 1 km resolution using the Barnes technique
247 (Barnes, 1964, 1973) and the time-varying lapse-rate as described in Liston and Elder (2006). Finally,
248 because the quantile-quantile correction with the E-OBS grid had the drawback of leaving residual
249 biases at the local scale, a final correction was applied at a monthly scale using the local climatology
250 estimated from the climatic station located in Sète.

251 **Impacts of climate change on the Thau hydrological budget**

252 To assess the impacts of climate change on the hydrological budget of the Thau catchment, the Soil
253 and Water Assessment Tool (SWAT) hydrological model was selected. SWAT is a continuous and
254 physically based hydrological model developed to study the effects of climate change and land
255 management practices on water (Arnold et al., 1998). The model has been successfully applied to
256 watershed modeling in the Mediterranean, particularly in the Thau catchment (Sellami et al., 2013,
257 2014). SWAT was implemented and calibrated against historical discharge data to estimate the water
258 budget of the whole Thau catchment. Then, the model was driven by the ensemble projections of the
259 selected climate models for a reference period (1971-2000) and a future period (2041-2070) to
260 investigate the potential impact of climatic change on some hydrologic metrics, including changes in
261 climatic conditions through assessing alteration in monthly precipitation and temperature previously
262 described and changes in catchment flow regime through assessing changes in monthly runoff in the
263 Thau catchment. Projected changes in climatic conditions for the future period were assessed by
264 calculating the multi-climate models ensemble (CME) average relative deviation for monthly
265 cumulative precipitation and absolute changes in monthly temperature with respect to the reference
266 period (1971-2000).

267 **Analysis of water uses and water use rivalries**

268 In this study, the water managers are representatives of one category of stakeholders in charge of the
 269 water resource management and/or of its allocation. Following the Decree defining the Thau Local
 270 Water Authority composition, the number of water managers is about 26. The most relevant players,
 271 called key stakeholders, were contacted, and a questionnaire was built using the outputs of
 272 preliminary interviews with them. This questionnaire was composed of both closed and open questions
 273 (Beaud, 1996). The questionnaire was divided into 5 sections, containing a total of 32 questions for
 274 water users and 40 questions for water managers. A list of proposed and possible water uses was
 275 commonly defined for all the case studies of the CLIMB project. This list of water uses is provided in
 276 the x-axis of Figure 3.

277 Questionnaires have been implemented by an interdisciplinary team (geography, social anthropology,
 278 political science). Appointments were made with at least one person representative of each water use
 279 and water use management. To collect the maximum amount of information to analyze the water uses
 280 and water use rivalries, semi-structured interviews and completion of the questionnaires were
 281 performed for each stakeholder. A total of 21 qualitative questionnaires were collected, and 46 semi-
 282 structured interviews were recorded and analyzed (Table 1). In these 21 questionnaires, the main
 283 water uses of the area and the all the spatial scale of water management are represented, as shown
 284 below in the list provided in the Social Network Analysis.

285 **Table 1: Implementation of the interviews and questionnaires in the Thau case study**

THAU	Water managers	Water users	TOTAL
Preliminary interviews	17	8	25
Questionnaires submitted	23	20	43
Questionnaires filled in	11	10	21
Total of interviews	28	18	46

286
 287 The first four sections of the questionnaire have been summarized and organized in a matrix with a
 288 column for each question and a row corresponding to each actor. The processing mainly consisted of
 289 regrouping the answers into categories and counting the occurrences to identify the major themes,
 290 terms, and answers that stood out. These outputs are used to present the major water uses and water
 291 rivalries according to stakeholders.

292 Then, the analysis was performed by listening in detail to the content of the interviews. Some
293 additional information from the literature, supplemented by discussions with scientists of the
294 CLIWASEC cluster, also contributed to the interpretation of results.

295 For more information on the content of the questionnaire or the on-site investigations, the reader can
296 refer to the CLIMB reports on the CLIMB website (<http://www.climb-fp7.eu>).

297 **Social network analysis of local water management**

298 A social network analysis (SNA) was made on the basis of the 5th section of the questionnaire
299 (Wasserman and Faust, 1994). The basic idea of SNA is to reconstruct stakeholder intervention in
300 policy processes (Knoke, 1990). For focusing on the relations between individuals, groups and
301 institutions, the SNA approach is particularly adapted to studying the actual interactions between
302 multiple stakeholders in the field of water management and water access competition.

303 SNA measures betweenness centrality through the question of contact frequency. Betweenness
304 centrality is the number of times an actor is on the shortest path between two other actors. It is the
305 most prominent centrality measure used to study power and dominance as it indicates an actor's
306 strategic position between other actors of the network. Actors having high 'betweenness centrality'
307 have better negotiation potential and control over the flux of information within the institutional
308 arrangement (Freeman, 1979; Christopoulos and Ingold, 2011). It gives insight here to the exact
309 position and role (beyond the delegation of legal tasks) of the different managers and users in the
310 integrated water resource management. Respondents were asked the following question: what is the
311 frequency of your contacts with the following stakeholders (a list of all the groups of stakeholders
312 interested with water use or water management was proposed. The acronyms relevant for the figures
313 in the section presenting the results are: ADENA, Natural Reserve of the Bagnas Ponds; AE-RMC,
314 Agence de l'Eau Rhône-Méditerranée Corse; Ass-Chasse, Association of hunting; CABT,
315 Communauté d'Agglomération du Bassin de Thau; Ceparlmar, Centre régional pour la promotion des
316 activités de cultures marines; CAHM, Communauté d'Agglomération Hérault-Méditerranée; COVED,
317 Wastes treatment society; CR-Conchy, Comité Régional Conchylicole de Méditerranée; CCNBT,
318 Communauté des Communes du Nord du Bassin de Thau; DREAL, Direction Régionale de
319 l'Environnement de l'Aménagement et du Logement; Ifremer, Institut Français de Recherche pour
320 l'Exploitation de la MER; PRUD, Prudhomie des pêches de Sète-Thau; SDEI, Société de Distribution
321 d'Eau Intercommunale; SIAE BL, Syndicat Intercommunal d'adduction d'eau des communes du Bas

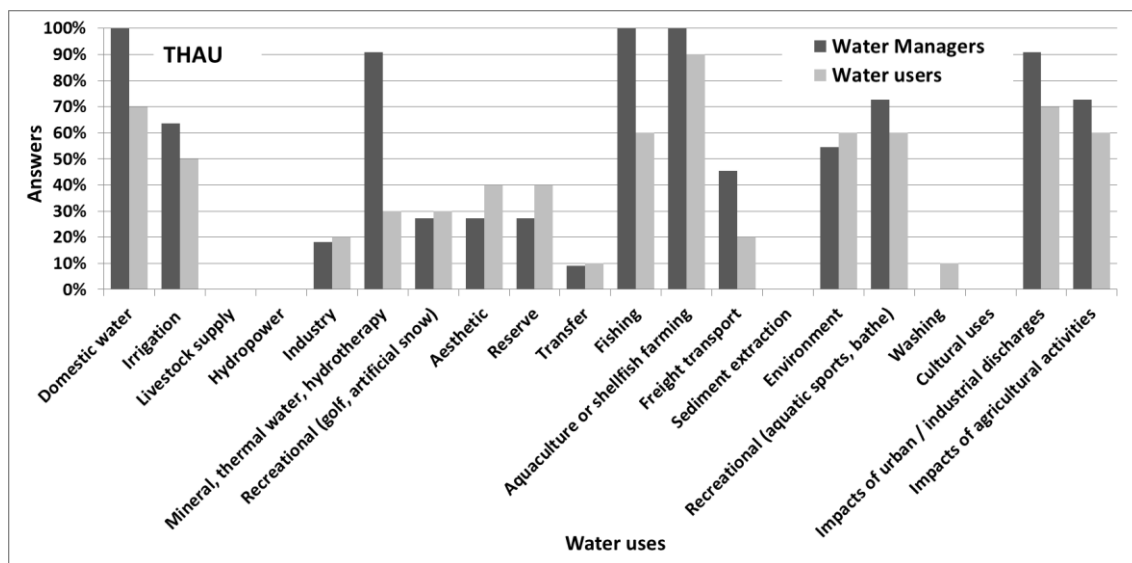
322 Languedoc; SMBT, Syndicat Mixte du Bassin de Thau; Thermes, Balaruc-les-Bains spa). In the
 323 present analysis, we only consider frequent relations, i.e., monthly and weekly contacts. We assume
 324 that this frequency of contacts permits the identification of more active stakeholders of the local water
 325 network. The treatment of SNA has been achieved using Pajek software (Batagelj and Mrvar, 1998).

326 Results and Discussion

327 Local governance of the Thau water quality restauration

328 *Perception of the hydrosystem by stakeholders*

329 Shellfish farming emerged as the major water use for all the interviewed stakeholders (regardless of
 330 whether they were water users or water managers). Fishing is also considered as a major activity by
 331 water managers, whereas water users perceive it as less relevant and of the same importance as spa,
 332 domestic water, fishing and freight transport (Figure 3).



333
 334 **Figure 3: Major water uses of the Thau according to water managers and water users interviewed**

335 There is a large difference in the importance of domestic use according to water users while, in fact,
 336 managers know this water use constitutes a significant portion of total water consumption throughout
 337 the basin.

338 It is worth noting that answers differ from water users and water managers for spa and freight
 339 transport. While almost all of the water managers interviewed considered the water use for spa to be
 340 major for the area, the water users considered it mainly as a minor use or did not consider it at all. The

341 answers regarding freight transport are mitigated and prove the lack of representation of the activities
342 of the channel connecting Sète to the Rhône.

343 Environmental use, as a recreational use, is not considered by all the managers to be a major use; in
344 fact, it was not even considered by water users. As rivers are all intermittent, except for mainly the
345 Vène, which generally has a basic flow ensured by its link with the karstic network, the other rivers
346 have no ecological flow to be maintained. The flow is generally represented by water treatment plant
347 discharges. Interest for the rivers are not comprehensively mentioned even by environmental
348 protection associations more focused on wetlands, biodiversity and water quality in the lagoon.
349 Furthermore, the rivers are difficult to access and do not attract any recreational use on the catchment
350 area. This contrasts with the answers for the consideration of the point and diffuse pollution impacts
351 considered as major for both water managers and water users. Livestock, hydropower, recreational,
352 aesthetic, reserve, washing and cultural uses are not mentioned as major.

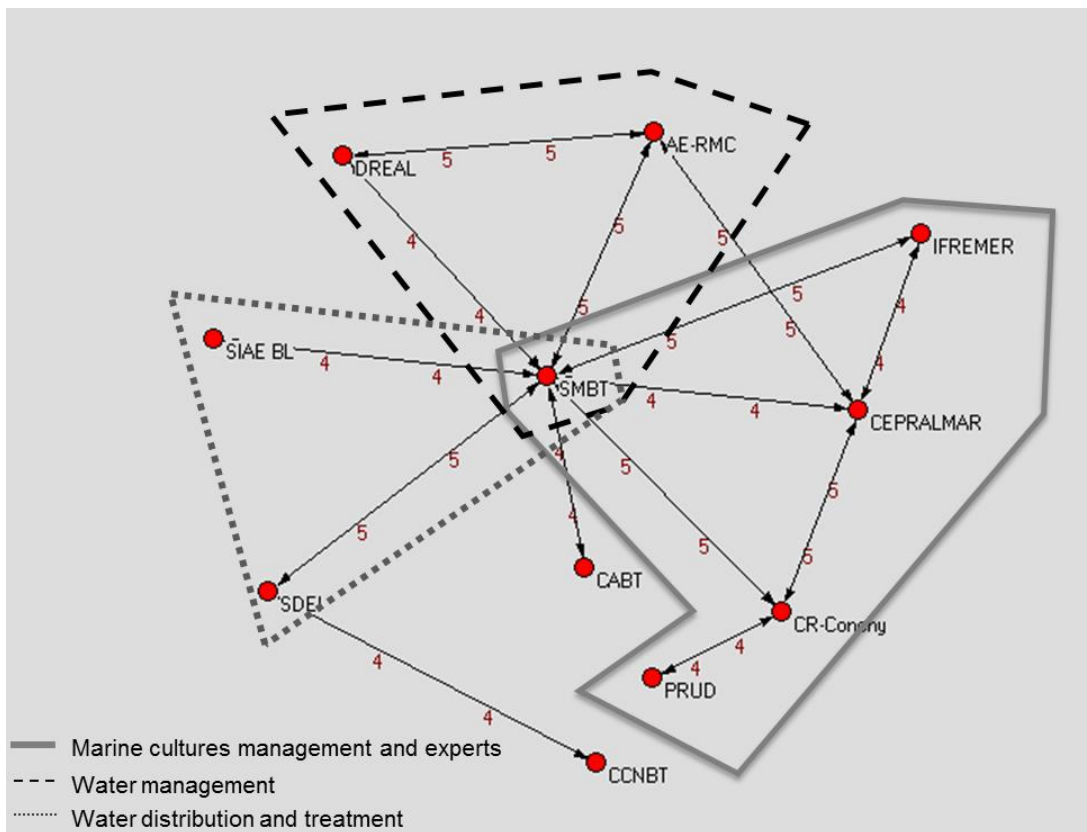
353 One can also highlight the absence of the perception of water transfer in this area for both water
354 managers and water users. The transfer of water is mentioned only once as a major water use which
355 proves that the local water management is really concentrated on the Thau lagoon and does not
356 address the problems and pathways related to water transportation and treatment for drinking usage,
357 despite the fact that the Aqua Domitia project was already initiated during the interview period. This is
358 in part also due to complex interconnections of the new water transportation plants that make it difficult
359 to know exactly where the water is coming from.

360 The Balaruc-les-Bains spa is the second most important French station. The exploitation of deep
361 surges is dependent on the state of the karstic aquifer; thus, because of the inversac phenomenon
362 already described, great difficulties have been experienced in the past due to conflicting requests from
363 fishermen and spa water users.

364 A point which is also far from the situation within the case study concerns the importance of industry in
365 the territory according to stakeholders. The Thau lagoon is lined with chemical industries for the
366 production of fertilizers and a factory for concrete. Moreover, the plants of these industries are
367 particularly visible around the lagoon. However, stakeholders from these industries have all declined
368 our solicitation for this study. The absence of industries in the LWC can also be mentioned even if
369 they are officially perceived as being represented by the CCI (Chamber of Trade and Industry).

370 **The social network of the local water management**

371 The intensity of contacts between stakeholders is represented in Figure 4. Highly connected
 372 stakeholders include the following: DREAL and the water agency (AERMC) which represent local state
 373 representatives and are directly concerned by the implementation of the WFD; SIAEBL is the most
 374 importation water production syndicate for the Thau territory; SDEI coordinates wastewater treatment;
 375 CABT and CCNBT are the two main groups of municipalities of the Thau territory; Ifremer is a
 376 research Institute that locally investigated the surveillance of water quality of the Thau lagoon and the
 377 safety of shellfish for commercialization; Cepralmar is the regional center for promoting the production
 378 of marine cultures; and CR-Conchy is the regional council for the marine cultures survey, while PRUD
 379 is the local representative of marine culture activities.



380

381 **Figure 4: Betweenness centrality within the water social network. The frequency of contacts represented**
 382 **is monthly for the value 4 and weekly for the value 5. Acronyms are defined in the section presenting SNA**
 383 **methods.**

384 The graph in Figure 4 reveals that water uses and water managers are highly connected (weekly
 385 contacts with the value 5 and monthly contacts with the value 4). Stakeholders are in direct and
 386 frequent contact with SMBT (eight nodes) except for CCNBT. However, such absence of a link

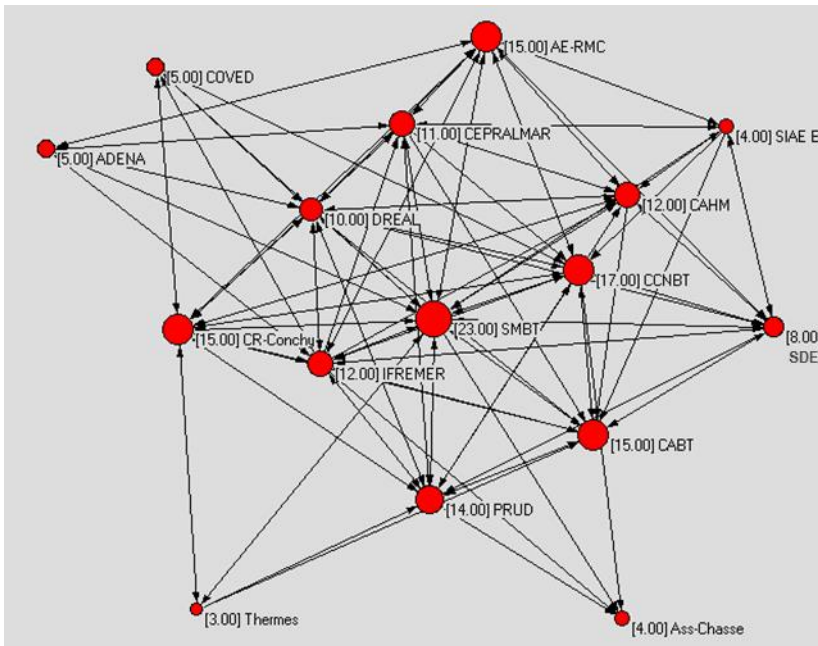
387 between two stakeholders does not mean a complete lack of connection, just rather occasional
388 connections. SMBT has the highest betweenness centrality making it in a very influential position as it
389 connects many stakeholders together. Three other stakeholders have three nodes of connection:
390 Cepralmar, AE-RMC and CR-Conchy. These are key stakeholders for the network as they provide
391 contact with other parts of the network.

392 The analysis shows that SMBT is the only stakeholder which connects three sub-networks: (i) the first
393 handles marine production comprising shellfish farming and brings together research expertise on
394 both environmental and farming issues (Ifremer) and local and regional managers of marine
395 production (PRUD, CR-Conchy, Cepralmar); (ii) the second relates to water management with water
396 policy implementation (AERMC, DREAL); and (iii) the third addresses drinking water production and
397 supply (SIAEBL, SDEI) and waste treatment. Communities of communes (CABT and CCNBT) can be
398 considered more external to these sub-networks and are connected through SMBT. SMBT is the most
399 central and influential stakeholder as it connects, directly or indirectly, all the local stakeholders. This
400 position is confirmed by the importance of transfer of information as shown Figure 5 and Figure 6,
401 SMBT is central both for the centrality in (they receive information from the stakeholders of the water
402 network, Figure 5) and the centrality out (they provide information to stakeholders of the water
403 network, Figure 6).

404 What is also important is that sub-networks (i) and (ii) represent the Lagoon Monitoring Network
405 (LMN). This network, established in 2000 to diagnose, on the basis of a set of several indicators, the
406 different ecological statuses of compartments of lagoon ecosystems in 23 lagoons of the LR region.
407 This network objective was clearly presented as a way to build governance on a network linking
408 managers and scientists. The fact that LMN was hosted by Cepralmar also complies with the priority
409 given to the use of the lagoon waters for shellfish farming. In fact, this water use, as one of the most
410 exigent regarding water quality and economically very important for the territory, was considered to
411 integrate all water uses of the catchment and coastal lagoons.

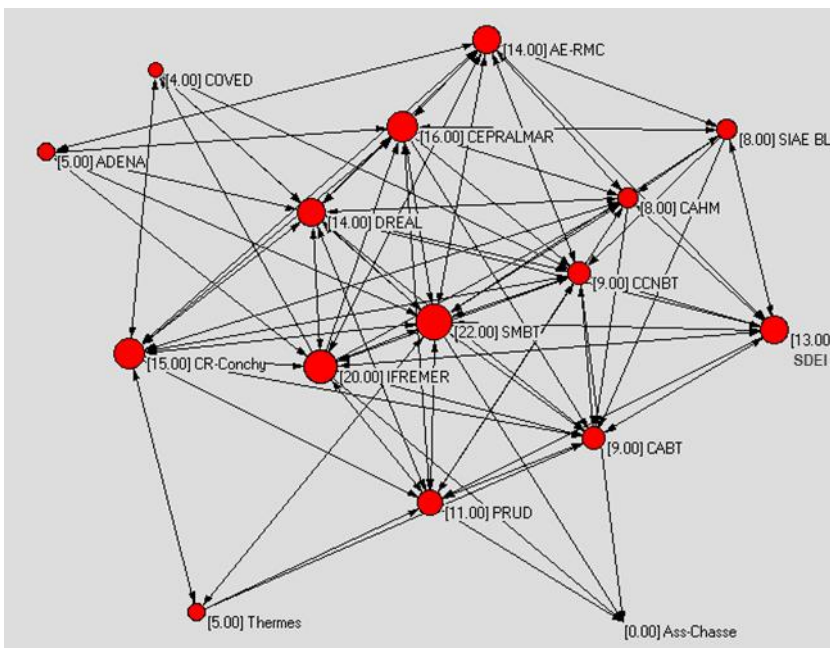
412 In summary, SNA confirms the central position of SMBT and the strong focus of water management
413 towards lagoon water quality and shellfish farming. The Water Agency (AE-RMC) nevertheless keeps
414 a prominent role in local water management issues. The governance of network type is very important
415 in the local water management of the Thau catchment, and it involves a mix of public and private

416 actors, including municipalities and the regional water basin authority on the public side. The French
 417 government (DREAL) has a relatively peripheral position.



418

419 **Figure 5: Centrality in for stakeholders in the Thau case study. Numbers represent the number of arrows**
 420 **directed to the node. Acronyms are defined in the section presenting SNA methods.**



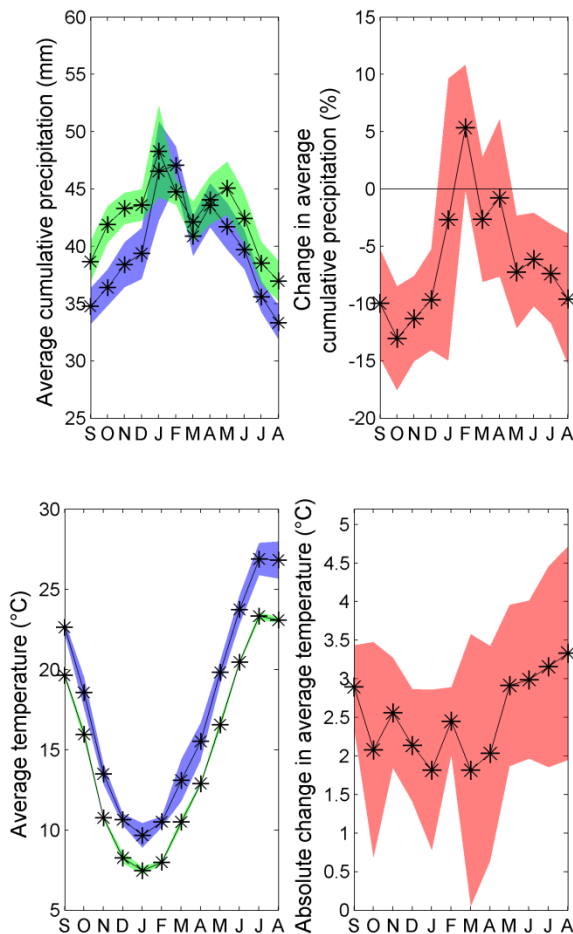
421

422 **Figure 6: Centrality out for stakeholders in the Thau case study. Numbers represent the number of arrows**
 423 **directed from the node. Acronyms are defined in the section presenting SNA methods.**

424 **Does climate change threaten the Thau territory?**

425 ***Climate change impacts on the Thau territory***

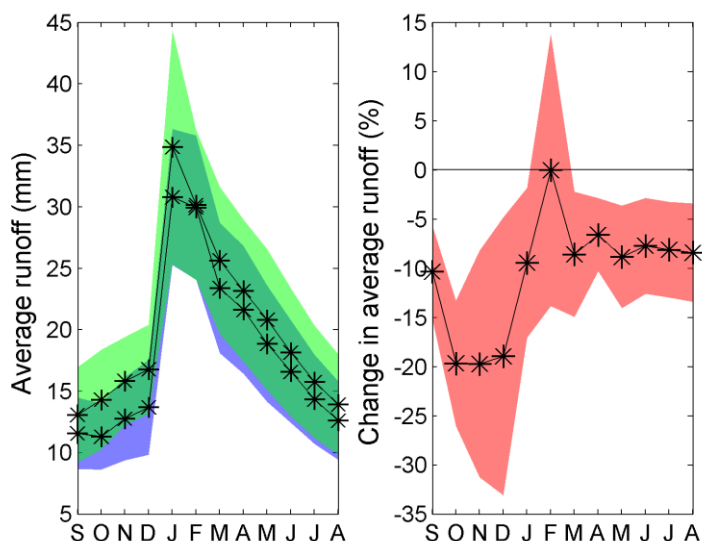
426 While the projected precipitation closely follows the seasonality and the monthly variability of the
 427 reference period, there is a clear tendency to a generalized decrease in the magnitude values across
 428 all months over the Thau catchment (Figure 7). This reduction is expected to range from -14 to -2%
 429 according to the CME mean values. An exception is made for February where the mean trend projects
 430 an increase of +5% in precipitation. However, the CME uncertainty interval suggests further decrease
 431 ranging from -18 to -5% from September to December, from -14 to +10% from January to April and
 432 from -15 to -2% in late spring and during the summer months. These values reflect the large
 433 uncertainty and variability in CME projections particularly in the winter months.



434
 435 **Figure 7: Projected change in reference cumulative precipitation (upper panel) and average monthly**
 436 **temperature (lower panel) as predicted by the ensemble multi-climate models in the Thau catchment.**
 437 **Light gray (green) represents the reference period (1971-2000) and dark gray (blue) represents the future**
 438 **period (2041-2070). The black line with black stars refers to the mean value.**

439 When comparing the magnitude of the average monthly temperature projection with that of the
440 reference period, there is clear evidence that climate models become more uncertain in simulating
441 temperature in the 2050s. All climate models project a general tendency towards warmer conditions
442 over the Thau catchment. The projected magnitudes of change suggest that the reference monthly
443 temperature is likely to increase by 1.7 to 3.2°C depending on the season. The highest increase in
444 temperature is projected for summer months when the summer season (JJA) reference average
445 temperature will increase by 3.1°C in the 2050s according to the mean value of CME. In contrast with
446 precipitation, the projected uncertainty in the magnitude of change in temperature decreases from the
447 dry months to the wetter months. By considering the uncertainty range of the values, the average
448 monthly reference temperature is likely to increase by 2 to 4.6°C in summer, 1 to 3°C in winter, 0.1 to
449 4°C in spring and 0.7 to 3.4°C in autumn.

450 These new warmer conditions would exacerbate the evapotranspiration process with a potential
451 increase in irrigation needs. In the meantime, the water balance will also decrease with decreasing
452 precipitation, with implications for runoff. Indeed, there is a clear tendency to less runoff in the future
453 with respect to the reference period in the Thau catchment (Figure 8), with a marked decrease in the
454 wet months, from October to December, with an average reduction of -20% with respect to the
455 reference value. Summer monthly runoff is also expected to decrease with an average value of -8%.
456 However, there is an increasing uncertainty in the projected relative change of the reference runoff
457 from the dry period to the wet period. Runoff is expected to decrease in the 2050s by a range between
458 -13 and -3% in summer, between -33.8 and -1.8% in winter (without considering February), between
459 -31 and -5.5% in autumn and between -10.3 and -2.2% in spring.



460
 461 **Figure 8: Projected change in reference runoff as predicted by the ensemble multi-climate models in the**
 462 **Thau catchment. Light gray (green) represents the reference period (1971-2000) and dark grey (blue)**
 463 **represents the future period (2041-2070). The black line with black stars refers to the mean value.**

464 In general, due to the combined decrease in precipitation and increase temperature, it is very likely
 465 that the Thau catchment will experience a general tendency toward less availability of freshwater in
 466 the future with respect to the reference period. This will induce a decrease in freshwater input into the
 467 lagoon and probably an increase in water salinity. Moreover, these results do not consider the possible
 468 additional impacts of the decrease in runoff on the recharge of the karstic aquifer in both baseline
 469 discharge in the Vène River and the on unassessed volumes of freshwater entering the lagoon via
 470 underwater springs as the Vise aforementioned.

471 ***Rivalries between water uses***

472 First, all water uses mentioned are potentially in competition with one another in the Thau lagoon. The
 473 only use which does not generate any mention of dispute or competition is industrial use.

474 There are many disputes in the Thau lagoon, and the list of rivalries provided by stakeholders is
 475 mainly related to water quality in the lagoon. The disputes mentioned all date back to less than 10
 476 years. One user mentioned 1975-1990 as a period in which water quality worsened significantly and
 477 when major anoxic crises in the lagoon started, affecting all uses of the lagoon with major conflicts.
 478 This user also explains that this gave rise to initial discussions between users.

479 The biggest number of responses refers to shellfish activity in the lagoon, and this is mentioned both
 480 by managers and users. The problems mentioned are those related to the loss in production or the

481 inability to sell shellfish due to water quality problems in the lagoon (microbial contamination and
482 anoxic crises due to eutrophication). These problems are described as being not completely resolved;
483 also, the awareness of these problems is improving following a number of study and research
484 programs undertaken to predict and anticipate crises and which involve decentralized government
485 services and local authorities.

486 The spa activity in Balaruc-les-Bains is also mentioned by both users and managers as provoking
487 frequent disputes with fishermen. The inversac phenomenon is always associated with problems,
488 although the complexity of this phenomenon makes it difficult to clearly identify causes for
489 stakeholders. While the spa is the more impacted activity during inversac, fishermen consider the spa
490 to be partly responsible.

491 Tourism is also mentioned both for its impact on water quality (due to urban waste or directly in the
492 lagoon due to recreational boats) and for the necessity to preserve bathing water quality in the lagoon.
493 Although the description of the impacts is vague, this use is perceived to be routing water away from
494 other activities: spa, environmental and freshwater users highlight the need to fight against salinization
495 of the lagoon in the summer. Irrigation seems to be a very local problem only in one town (Villeveyrac).
496 The impact of ferti-irrigation of vineyards using chemical products and the need for acids to clean the
497 pipes is described in detail. The problem concerns both competition for the resource and the cause of
498 pollution.

499 As for issues unrelated to conflicts of use, the impact of the increase in salinity of water on fauna and
500 flora is mentioned without further detail.

501 As far as the described rivalries between water uses in relation to the quality of the waters of the Thau
502 coastal lagoon, climate change impacts, such as an increase in temperature and salinity of the waters,
503 are perceived to probably aggravate tensions between water users.

504 ***The regional water scarcity adaptation strategy including Thau territory***

505 In the Thau territory, demographic pressure is increasingly tough, not only because of the influx of
506 tourists but also due to the resident population. The latter has particularly accelerated since the
507 building of the strip of the A9 motorway which connects Nîmes, Montpellier, Béziers, Narbonne and
508 Perpignan to Spanish Catalonia via the Pyrenees. In fact, Montpellier is an employment hub, whereas
509 the basin of Thau has a high rate of unemployment; however, housing costs are very high in
510 Montpellier and its neighboring suburbs. The villages in the Thau basin are therefore highly sought

511 after as they are less than 40 km from Montpellier. The water sources of the catchment area have
512 never been sufficient to supply the population. Water from surges and aquifers has been imported
513 from the Hérault area for several decades with the exploitation of local surges currently degraded by
514 an increasing salinity. However, as mentioned above, in February 2012, water was routed from the
515 Rhône River within the framework of the regional Aqua Domitia project for distribution after treatment
516 by the SIAEBL Water Syndicate. This project shows how domestic use represents an important part of
517 water uses in the basin and how dependent the basin is now on external regions, despite being in the
518 same hydrographical district in view of the WFD.

519 **Coherence between regional and local water governance**

520 The great *malaïgue* of 1975 of the Thau coastal lagoon, an anoxic crisis related to eutrophication of
521 waters which affected the entire lagoon with the loss of all shellfish that had been bred, led all local
522 policies to focus on the necessity to recover the water quality of the lagoon to support one of the main
523 economic activities of the Thau territory: shellfish farming and fishing justified for its major input to the
524 socio-economic life of the region. A SMVM has been implemented to work on resolving conflicts due to
525 the diversity of human activities in the coastal zone, representing the intention to develop ICZM around
526 the Thau lagoon ecosystem. Scientific investigations of the quality of the lagoon were set up in
527 interaction with the study of the impacts of human activities from the catchment to understand the
528 connection between human activities and water quality of the lagoon. At that time, eutrophication was
529 the main threat according to nitrate (Plus et al., 2006) and phosphorous load assessments (La
530 Jeunesse et al., 2002; La Jeunesse and Elliott, 2004). The need to comply with the WFD permitted the
531 structuring of scientific data on the transitional waters of the LR Region through the regional initiative
532 to launch the LMN.

533 Presently, the work to provide an integrated vision of the water quality of the hydrosystem by the
534 SMTB has been a success as proven by the results presented here as (i) the capacity of all
535 stakeholders groups to make the link among water quality of the coastal lagoons, outputs from the
536 catchment and the support to shellfish farming and fishing activities; (ii) the intensive local water
537 network around the cornerstone actor SMTB which drives an efficient governance for the restoration of
538 water quality; and (iii) the dissemination of knowledge to all stakeholders through activities of the LMN.

539 The high quality database on the ecological quality of regional coastal lagoons maintained by the LMN
540 permitted the implementation of the LOICZ (Land-Ocean Interactions in the Coastal Zone)

541 biogeochemical budget methodology (Gordon et al., 1996) and led to the DSS tool called
542 O'GAMELAG (LMN, 2013). This DSS has been implemented in one regional coastal lagoon, Bages-
543 Sigean, and it was planned to for implementation in the Thau coastal lagoon. Those data are even
544 largely used to perform environmental impact assessment studies in the region by several public and
545 private bodies comprising Natura 2000 assessments. Thus, this database is supporting analysis to
546 preserve both the good ecological status of the lagoon in relation to nutrients and the shellfish farming
547 production in the context of urban development in the catchment. This high level of connection of
548 stakeholders is the result of twenty years of collaborative actions between stakeholders on the support
549 of scientific expertise. Local citizens still remember the difficulties of awareness and negotiations
550 steps, including several important local crises as the destruction of the Ifremer research center in 1987
551 by shellfish farmers who were, at that time, not aware of the new water quality issues in the coastal
552 lagoon. Communication among all water uses has been the only support of the integration of water
553 quality, but it has been supported day after day by relevant databases and models developed and
554 presented by local experts and grouped in LMN. Additionally, this capacity to restore water quality is
555 due to the dynamism of the SMBT to drive the local network because of its singular position as it acts
556 on the behalf of CABT and CCNBT.

557 This permitted the provision of a SCoT coherent with the SAGE. SAGE and SCoT both consider water
558 uses and water quality issues related to shellfish farming as the criteria of integration. Then, SMBT
559 provides clearly, even on its website, the need to control urban development on the territory to prevent
560 its possible unsustainable impacts on water quality of the Thau lagoon.

561 In this context, the provision of an 'unlimited' water resource to sustain the drinking water production
562 of the Thau territory by the new hydraulic connections and the forecasted regional mutation of
563 agricultural practices raise questions. This seems incoherent with the control of the urban spread and
564 the regulation of human activities development at risks for water quality. Environmental and long-term
565 water management concern have been clearly exposed during the public debate on Aqua Domitia
566 project as for the main points of the list relevant for the Thau territory: the decrease in awareness of
567 water economy, the heterogeneity for farmers to access to this new resource, the switch from several
568 to one unique source of water for drinking water production as local communities could not afford to
569 invest in both the maintenance of the old production system and the treatment of the water coming
570 from the Rhône River, the use of water by industrial instead of agricultural activities that has justified

571 investments for bringing water initially for irrigation, new water quality issues in the water bodies
572 induced by contaminants contained in water for irrigation such as PCBs and diuron that are a very
573 recent concern for the Thau lagoon, the intrusion of new pesticides in the drinking water even if they
574 remain on legal concentration after dilution with unpolluted sources of water, and so forth.

575 One interesting question for this paper was related to the governance of Aqua Domitia. The need for
576 trans-basin governance induced by the specificities of the Aqua Domitia project is claimed by
577 stakeholders with particular insistence from water managers. If the LR region recalled the vocation of
578 public interest, BRL, as the dealer, some participants do not state less distrust toward the potential
579 market behavior of this company. Furthermore, some studies have revealed the under-exploitation of
580 the water already dedicated to irrigation, and this could have been interpreted as an already existing
581 safety margin in the context of climate change impacts (Ghiotti and Honegger, 2009).

582 In the meantime, the Thau agglomeration (CABT) presented Aqua Domitia as a response to the
583 specific challenges of their territory. SAGE-Thau, which also participated in this public debate, used to
584 support Aqua Domitia project explaining it as the only way to ease pressure on the fragile aquatic
585 water bodies following studies conducted by the Water Agency. In fact, the impact of climate change
586 on the Thau hydrosystem which would manifest in a decrease in freshwater outputs from the
587 catchment to the coastal lagoon and its associated wetlands has even been confirmed by this study.

588 SAGE-Thau also defended the position of the absolute need to clarify the governance of this new
589 resource, and thus we think the establishment of regional versus local water governance will be
590 challenging in the coming years.

591 The 184 pages of this public debate report induced 3 pages of synthesis of the decisions from BRL.

592 The most important one for the Thau territory is that BRL has decided to participate, together with the
593 LR Region, in deploying a system of consultation with stakeholders and public information including
594 strengthening the system of information on water quality in collaboration with experts of reference in
595 the field of water quality. Thus, the network of stakeholders is equivalent to that represented the LMN!

596 However, because the LMN reached its goal of delivering an operational DSS to local stakeholders,
597 the LR region decided to end this network by not providing any financial support (representing less
598 than 300,000 euros per year) to a new plan of action. LMN ended in 2013, and the DSS O'GAMELAG
599 will not be implemented for the Thau stakeholders.

600 Thus, whereas (i) France has to answer to the European Union for its lack of a definition for vulnerable
601 areas related to the Nitrates Directive in the Thau catchment; (ii) the Thau catchment is ungauged
602 despite being regularly mentioned as a pilot site for integrated management in the coastal zone with
603 the creation of hydrological indicators; and (iii) the Thau territory has initiated a period of evolution of
604 the local water resource governance; the LR Region has denied local authorities of adequate scientific
605 expertise. The water quality expertise is no longer organized as one voice in the water network, and
606 the knowledge on several lagoons is no longer capitalized to deliver a consistent message on the
607 state of ecological quality of regional coastal lagoons necessary to provide new indicators to face
608 climate change impacts on the hydrosystem. Perhaps the next directive on Marine Spatial Planning
609 and Integrated Coastal Management would permit the network to re-establish, but, in any case, this
610 situation is a proof of the lack of awareness of climate change-induced impacts on local territories.
611 Thus, scientists have to continue their efforts of disseminating their results as highly requested, at
612 least, by the European Research Framework programs.

613 **Conclusions**

614 The results of the study presented in this paper expose that rivalries which took place in the past in the
615 Thau coastal lagoon are declared by stakeholders to be related to water quality issues in the lagoon.
616 Today, the water quality restoration is the result of twenty years of several multi-disciplinary programs
617 alternately conducted by scientists and by the local public bodies. Moreover, this has been possible
618 through two main factors. Firstly, as confirmed by the SNA outputs, through the central position of the
619 public body SMBT and the strong focus of water management towards lagoon water quality and
620 shellfish farming. Secondly, through the creation by the LR region of the LMN in 2000 to provide a
621 common knowledge base between stakeholders (both water users and water managers), experts and
622 scientists for implementing integrated management solutions for the transitional waters.

623 Climate change is likely to bring the context of relations between users of the water resource in tense
624 situations similar to those happened in the past. Specifically, 2050s projections indicate that yearly
625 mean precipitation is expected to decrease from about 2% to about 15%, while conversely
626 temperature is expected to increase on average from about 2°C to about 3.5°C. The temperature
627 increase will exacerbate the evapotranspiration process, leading to a dryer soil moisture conditions,
628 which will require larger water quantity for irrigation, while precipitation decrease will be obviously

629 reflected in lower runoff production. These critical changes will imply potential negative impacts on
630 water quality comprising anoxic crises.

631 In order to answer to climate change impacts, the LR region managed the Aqua Domitia project to
632 conduct freshwater from the Rhône to the Thau catchment to supply irrigation needs. This water is
633 already used for drinking water production supplying industrial, domestic and tourism water uses.
634 While the SMBT is devoted to control the urban spread and the regulation of human activities
635 development on its territory with the two main tools represented by the SCoT and the SAGE Thau, this
636 provision of an “unlimited” water resource can be considered as incoherent. Moreover, as this paper
637 demonstrates, the absence of perception of both water transfer and climate changes impacts, the
638 dissemination of threats due to climate change and the use of the untreated water of the Rhône River
639 or the water quality of the lagoon is really needed. The specificities of the Aqua Domitia requires a
640 trans-basin governance which could have relied on the existing LMN. However, the LR region decided
641 to end its financial support to the LMN in 2013! Since then, stakeholders no longer have contact that
642 can meet with an integrated approach to their problems. More importantly, the methods used to
643 resolve situations in the past could be inefficient for future situations. In the present state of knowledge
644 on the impact of climate change, it is likely that the chains of cause and effect for achieving the same
645 situation of deterioration of water quality are different. Thus, the tools previously developed, including
646 those offered by the LMN, although operational and valid today for some regional coastal lagoons, can
647 become obsolete if not updated continuously with the increase in knowledge about all the criteria
648 explaining the chain of cause and effect between climate change and water quality.

649 The political decision to end this network, beyond demonstrating a lack of appreciation of the issues of
650 the territory, can be much more problematic for some time as it will induce rearrangements of this
651 network. There is every reason to think the establishment of regional versus local water governance
652 will be challenging in the coming years. Indeed, by denying the territory to continue in developing its
653 own methods of water quality management, it increases the risk of development outside the
654 challenges of climate change, that is to say, unsustainable development or maladaptation. This
655 contributes to increase the vulnerabilities of the Thau territory to climate change impacts.

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