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The future of temporary wetlands in drylands under the global change.

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Abstract:	The Andalusian International University held a Workshop entitled Temporary wetlands' future in drylands under the projected global change scenario in March 2020 in Baeza, Spain, with 26 participants from 10 countries. The workshop objectives were to promote international cooperation and scientific exchange on the conservation and protection of temporary wetlands. The participants highlighted the extreme conditions that temporary and permanent wetlands, ponds and shallow lakes are currently facing, foreseeing a dismal future due to climate change. To foster a holistic view of these ecosystems, the workshop focused on wetlands including their watersheds. It was concluded that the main threats include those affecting water quality and quantity as well as those affecting egg-seed banks, species population dynamics, and trophic web features. Moreover, the inherent characteristics of water bodies in drylands and their general high resilience and resistance to harsh conditions are already negatively impacted by direct human actions and climate change. Another threat is the time lag between the issuing of scientific warnings and the social and political concern leading to mitigating actions. Thus, more effective actions to protect and conserve temporary wetlands are essential. Research networks could help propel the needed conservation actions, but the global recession due to the COVID-19 pandemic will pose a challenge as economies are burdened with urgent expenses. This special issue of the journal Inland Waters is the result of the workshop presentations and includes an overview on the topics discussed.
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Response to Reviewers:	The manuscript has been updated with the references that have been already accepted in the Special Issue. However, several articles are still under the review process. We hope the final list can be updated soon. We have added a figure to make more clear the connexion among the thematics blocks.

The future of temporary wetlands in drylands under global change

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Abstract

The Andalusian International University held a Workshop entitled *Temporary wetlands' future in drylands under the projected global change scenario* in March 2020 in Baeza, Spain, with 26 participants from 10 countries. The workshop objectives were to promote international cooperation and scientific exchange on the conservation and protection of temporary wetlands. The participants highlighted the extreme conditions that temporary and permanent wetlands, ponds and shallow lakes are currently facing, ~~foreseeing~~ a dismal future due to climate change. To foster a holistic view of these ecosystems, the workshop ~~focused on wetlands including their~~ watersheds. It was concluded that the main threats ~~include~~ those affecting water quality and quantity as well as ~~those affecting~~ egg-seed banks, species population dynamics, and ~~trophic~~ web ~~features~~. ~~Moreover, the~~ inherent characteristics of water bodies in drylands ~~and their general~~ high resilience and resistance to harsh conditions are already negatively impacted by direct human actions and climate change. Another threat is the time lag between ~~the issuing of~~ scientific warnings and the social and political concern leading to mitigating actions. Thus, more effective actions to protect and conserve temporary wetlands are essential. Research networks could help ~~propel~~ the ~~needed~~ conservation actions, but the global recession due to the COVID-19 pandemic will pose a challenge as economies are burdened with urgent expen~~ses~~. This special issue of the journal *Inland Waters* is the result of the workshop presentations and ~~includes an overview on the topics discussed.~~

Keywords: Temporary ponds, egg-seed banks, biodiversity hotspot, resilience, water quality, trophic web.

Temporary wetlands in drylands

Under global change scenarios, water shortages in drylands are projected to increase due to population increase, land use change~~s~~ and declining precipitation (IPCC 2014). From 1960 to 2000, the global use of fresh water (drylands included) expanded at a mean rate of 25% per decade (MEA, 2005). Consequently, we can expect increased pressure on aquatic ecosystems and aquifers ~~for~~ supply~~ing~~ more water, with negative impacts on the water regimes and biota of the wetlands (Brendonck et al. 2015, Kneitel 2016, Zadereev et al. 2020, Yılmaz et al. 2021). ~~The w~~etlands encompass diverse types, including endorheic water bodies, from tiny ponds to large chotts or sebkhas, ~~but also~~ temporarily flooded margins of permanent bodies such as streams and lakes. In the following, we use the term “wetlands” in a general sense to include marshes and swamps, as well as ponds and shallow lakes in drylands.

Although wetland ecosystems are among the most threatened globally (MEA 2005) they support a high species richness, including the dormant components (egg and seed bank) of many communities (Brendonck and De Meester 2003, Brock 2011), making them a significant part of global biodiversity (Williams 2006). Additionally, they provide habitats for many animals, including nesting and feeding birds, and plants. Although the general public has ~~little~~ awareness of the existence of wetlands, these aquatic ecosystems have gained increas~~ed~~ attention ~~in different countries~~ after ~~they~~ became contracting parties to the Ramsar Convention on Wetlands. The resulting reports and studies published during the past ca. 50 years on the sustainable use of different types of wetlands and the services that they provide have increased ~~the~~ awareness of the~~ir~~ need for protection. ~~This includes~~ Resolution VIII.33 (Ramsar 2002) ~~that~~ highlights temporary wetlands as “Wetlands of International Importance”. This increasing understanding of the value of these ecosystems by conservationists stands in stark contrast to the overall disinterest displayed by policy and decision makers who largely fail to recognise the importance of these ecosystems (Ramsar Convention on Wetlands 2018).

Hydrological characteristics (duration, depth and their variations within and between years) are ~~amongst the~~ main factors influencing the ecological functioning of wetlands (Keddy 2000, Brendonck et al. 2015, 2017). ~~But l~~and use change~~s~~, agricultural intensification and other indirect global impacts have become common drivers of change in drylands (Yılmaz, 2021). The ~~existence of~~ lag time between the identification of issues by scientists and the social and political responses is another ~~identified~~ threat. For th~~at~~ reason, new or better regulation and management planning, based on scientific information, are essential, as discussed at the workshop.

Our objective with this paper is to summarise the conclusions of the workshop *Temporary wetlands' future in drylands under the projected global change scenario'* held ~~by~~ The Andalusian International University in March 2020~~ and of~~ the papers presented in this special issue. Five ~~thematic blocks~~ were highlighted to give a general picture of the present and future conditions and the challenges faced by temporary wetlands. The themes included were: (i) water quantity and quality; (ii) egg and seed banks; (iii) ecological resilience; (iv) role of ~~trophic~~ web maintenance and (v) role of temporary wetlands as hotspots of biodiversity. We acknowledge, of course, that issues not ~~treated~~ at the workshop, such as invasive species, may be of importance as well. Each ~~thematic block maintains~~ connect~~ions with the rest~~, as a characteristic feature of complex systems, ~~which must lead to the explore for~~ complex solutions ~~too~~ (Figure 1).

Water quantity and quality

Changes in precipitation and evapotranspiration patterns due to climate change (IPCC 2014) have in some areas increased the duration of dry periods (Döll and Zhang 2010) with major implications for small aquatic ecosystems (Rosset et al. 2010; Tuytens et al. 2014; Pinceel et al. 2018). They are also threatened directly (i.e: agriculture; MEA 2005) and indirectly by various human activities and pressures (i.e. global change; Phillips et al. 2015). Global change has already affected the duration and extent of flooding of existing temporary water bodies and some previously permanent water bodies have now become temporary (Yılmaz et al. 2021). Shorter hydroperiod lengths, as a consequence of reduction in rainfall, and higher temperature result in shortened growing seasons for aquatic biota and thus introduce more rigid time constraints on maturation and reproduction, reduce population growth rates and increase the risk of extinction (Tuytens et al. 2014, Pinceel et al. 2018). Aquatic-breeding amphibians are also vulnerable to changes in wetland hydrology (Walls et al. 2013). Variation in wetland hydroperiods due to precipitation extremes ~~has been shown to~~ reduce the number of egg clutches and adult amphibians and affect the timing of amphibian reproduction, which in turn may modify the composition of communities and interfere with the ~~dynamics of~~ competitive and predatory interactions. The severity of the effects will depend upon the individual species, its propensity for phenotypic plasticity and the life history stage that is impacted.

~~Considering this,~~ temporary wetlands are particularly sensitive to anthropogenic pressures (Rhazi et al. 2001; Bouahim et al. 2014) and climate change (El Madihi et al. 2017; Pinceel et al. 2018). For instance, in Morocco, climate projections reveal that the water deficit could increase by 16% to 67% in 2100 under the RCP8.5 scenario (Representative Concentration Pathway 8.5 delivers a temperature increase of about 4.3˚C by 2100) (Grillas et al. under review). The flooding duration ~~would~~ decrease substantially and some wetlands will dry out completely (Grillas et al. under review). Moreover, increased duration and intensity of drought are likely to favor the spread of wildfires, which may ~~cause a transitory alteration of~~ faunal diversity patterns across wetlands (Cunillera-Montcusi et al. under review).

The workshop participants further highlighted that climate change and water abstraction may result in substantial water level fluctuations, with potentially major effects ~~even~~ on the vegetation and associated organisms in the littoral zone of permanent water bodies, especially ~~the~~ fish populations (Strayer and Findley 2010, Zohary and Ostrovsky 2011, Cummings et al 2017).

~~Likewise,~~ the reduction of the water volume in wetlands will ~~also~~ affect ~~the~~ water quality (Zeng et al. 2013, Vega-Pozuelo 2018). Climate change can exacerbate symptoms of eutrophication (Moss et al. 2011, Jeppesen et al. 2014) ~~as~~ prolonged exposure to high nutrient loading has severe effects on wetland structure and functioning (Sánchez-Carrillo et al. 2010, García-Muñoz et al. 2010, Gilbert et al. 2017). The increased temperature and frequency and duration of drought will also lead to increased salinization affecting around ~~1/3~~ of freshwater bodies (Jeppesen et al. 2020). Salinization effects have been poorly studied compared with other environmental problems, but have gained increasing interest due to climate change (Waterkeyn et al. 2008, 2010b, 2011; Jeppesen et al. 2015, Cañedo-Argüelles et al. 2016, Vidal et al. 2021). ~~Enhanced~~ salinity has adverse effects on the fitness and survival of many aquatic organisms and on ecosystem functioning and, consequently, on ecosystem services that wetlands provide (Vidal et al. 2021).

Besides salinization, wetlands are also facing increased stress ~~by~~ other chemicals, notably agrochemicals. The risk of pesticides pollution is greater in ~~those~~ areas ~~that may suffer~~ a water deficit under future scenarios (Tang et al. 2021). While some of the tools and methodologies used in aquatic toxicology have been essential for developing water quality guidelines (WQGs) by establishing legal maximum concentrations for many pollutants (including salt) for different aquatic species (Nugegoda and Kibria 2013), it ~~was emphasized at the workshop, that it~~ is time now to do more studies under more realistic conditions~~,~~ that account for ~~the~~ complexity ~~existing~~ at the ecosystem level (Jeppesen et al. 2020). These ~~also~~ include multiple stressor effects (e.g. salinization, eutrophication and chemical pollution) together with changing hydrology (Waterkeyn et al. 2008, 2011; Arenas-Sánchez et al 2016). Although knowledge about the effects of multiple stressors at the community and ecosystem level has increased recently (Segner et al. 2014, Birk et al. 2020), we are still far from having achieved a general understanding. It is necessary to move beyond the classical approaches, if we want to identify direct and indirect effects of multiple stressors and develop relevant mitigation methods (Rico et al. 2016). ~~Especially,~~ the interaction among pollutants and the direct and indirect effects of climate change have been little studied in temporary wetlands and ~~has~~ so far mainly focused on effects, but less on solutions (Parra and Ramos-Álvarez, under review). The lack of ~~responses and~~ solutions is leading to the loss of wetland integrity through pollution and water quality deterioration unexpectedly in protected ecosystems. Two examples ~~of this~~ were presented at the workshop: (1) Doñana National Park (southern Spain) where human activities have intensified over the last few decades, affecting the water quality (and quantity) despite its environmental importance (Paredes et al. 2019), and (2) the Fuente de Piedra wetland (southern Spain) that is affected by wastewater discharge (De-los-Ríos-Mérida et al. 2017).

It is evident that mitigation of the effects of eutrophication, salinization and agrochemical pollution are of key importance for preserving the water quality of wetlands (Jackson et al. 2016, Cui et al. 2020) and new guidelines in environmental risk assessment are needed (Geissen et al. 2015). Nature-based solutions (NBSs) may be a way forward. As an example of NBS, De-los-Ríos-Mérida et al. (2021) found a slight improvement in the quality of wastewater effluent passing through a stream with artificial wetlands for natural purification before entering a Ramsar wetland (Fuente de Piedra, southern Spain).

There are trade-offs, however, between protecting ecosystem integrity and guaranteeing human welfare (social and economic components of sustainable development), which need to be considered, and it is likely that a cocktail of approaches is needed when weighing the environmental benefits of reducing the levels of contamination against the economic, social and other environmental costs of the adopted action(s) (Van den Brink et al. 2018). However, as wetlands do not ~~have~~ sufficient attention or recognition from policy and decision makers, reinforcement of laws and regulations is crucial when implementing restorative measures.

The fate of egg and seed banks under climate change

A major but often overlooked component of temporary wetlands is banks of eggs and seeds in the wetland sediment~~, of~~ specialised higher plant groups, zooplankton, large branchiopods (Bonis et al. 1995, Brendonck and De Meester 2003, Olmo et al. 2020) as well as other resting stages such as bacterial endospores, akinetes of cyanobacteria, and cysts and spores of various protists (Souffreau et al. 2013). These banks of drought-resistant propagules remain viable for an extended period of time in a state of dormancy (resting stage with a strongly reduced metabolism). Only a few higher plant species are restricted to the aquatic stage (hydrophytes); most are amphibious and survive, at least for some weeks, after a wetland dries out. However, especially in dry summer climates, only plant species having an annual life cycle with high seed production tolerate the alternation between dry and flooded phases (Rhazi et al. 2001, Brock 2011). For example, 70% of the plant species present in Mediterranean temporary wetlands are annuals (Médail 2004).

While some aquatic invertebrates permanently inhabiting temporary wetlands produce dormant propagules during the sexual phase of their life cycle (as most rotifers and cladocerans ~~do~~), other species are obligate sexual reproducers and produce resting eggs in anticipation of deteriorating conditions (copepods) or during their entire lifespan (large branchiopods) (Brendonck et al. 2017, Belmonte, 2020). Some ostracod species have both sexual and asexual populations that also reveal diverse dormancy strategies (Mesquita-Joanes et al. 2012).

The longevity of eggs and seeds in the soil of temporary wetlands affects egg and seed bank richness and size (Bonis et al. 1995, Brock 2011, Olmo et al. 2020). Dormant eggs of zooplankton and large branchiopods can survive for extended periods in the dry sediment of temporary wetlands (Brendonck and De Meester, 2003), and also some seeds may persist for prolonged periods when buried (Poschlod and Rosbakh, 2018). When the inundation phase of temporary wetlands lasts long enough, egg loss due to ~~egg~~ mortality and hatching from the egg bank will be compensated by the production of new resting eggs that accumulate in the soil. To buffer for unsuccessful hatching, and similar to the hatching strategies in desert annual plants, not all eggs will hatch at any ~~opportunity,~~ but will do so when triggered by suitable conditions and with fractions that theoretically reflect the local long-term chance for successful reproduction (bet-hedging as part of a risk-spreading strategy) (Pinceel et al. 2017; Gremer and Venable 2014). Under normal conditions, the above processes will, in the long term, result in a positive egg and seed bank budget that can buffer against the typical natural intra- and inter-seasonal climate variations of temporary wetlands. Ongoing and future climate change may disturb these fine-tuned processes and not only impact on the structure and functioning of the active~~, but also of the dormant (egg bank)~~ components of the plant and animal communities of temporary wetlands on which the demographic resilience and persistence of populations depend (Pinceel et al. 2018). Making use of a population matrix model, Pinceel et al. (2016a) underlined the importance of long-term survival of resting eggs under a critical hydroperiod for persistence of local temporary rock pool populations.

Due to ongoing and future climate change, shallow permanent wetlands may gradually become semi-permanent or even dry out seasonally with accompanying changes in the aquatic communities in the direction of more drought-adapted species that disperse mainly by means of their dormant propagules. For example, ~~a~~ gradual historical climate change with increasing aridification was the driver for diversification in Australian *Branchinella* (Anostraca) species (Pinceel et al. 2013). However, the current speed of climate change might be too fast for local populations to produce sufficient numbers of eggs to replenish the egg bank (Tuytens et al. 2014) or to adapt and accelerate growth and maturation rates. Also, in plant communities, changes in the timing and duration of flooding, as expected under climate change, will induce alterations in the composition and abundance of species (Bliss and Zedler 1997, Grillas and Battedou 1998). Similar to animals with egg banks, a reduced wetland hydroperiod will result in a diminished seed bank density of plants and hence increased probability of population extinction (Faist and Collinge 2015, Grillas et al. under review).

During the predicted prolonged periods of drought, egg banks will be exposed for an extended duration to more frequent and more intense winds (Pinceel et al. 2020) that will lead to impoverished egg banks (Brendonck and Riddoch 2000) and community structure changes (Pinceel et al. 2016b). Most probably, the same mechanisms apply for wetland vegetation and seedbanks with large inter-species differences in dispersal propensity and rate, probably resulting from differences in seed size (Grillas et al 1993a).

Changing temperatures with more frequent and intensive heat waves will also directly impact the dry egg bank, reducing egg hatching and survival (Brendonck et al. 1996, Pinceel et al. 2018). ~~Also p~~lant seed germination will be affected, as most plant species germinate at low temperatures as an adaptation to a winter-centred flood period, although species differ in their optimum and breadth of the germination niche (Bonis et al. 1995, Carta et al. 2013).

Dispersal of dormant eggs ~~between~~ wetlands can be affected by wind, overflows, water birds and mammals, including humans (Green et al. 2002, Vanschoenwinkel et al. 2010, Waterkeyn et al. 2010a, Lovas-Kiss et al. 2018) and involves interaction between the communities of temporary wetland clusters (Lopes et al. 2016, Brendonck et al. 2017). In such a metacommunity design, specific wetland patches can function as source, sink or refuge. If some wetlands become uninhabitable due to climate change, the distance for successful dispersal between wetlands may increase and impact wetland metacommunity dynamics (Tuytens et al. 2014).

As ~~it has been~~ mentioned ~~in the previous section,~~ and being one of the major indirect stressors induced by climate change (Waterkeyn et al. 2008, 2010b), increased salinity has been shown to impact egg banks as well as active communities of large branchiopods in Mediterranean temporary wetlands (Waterkeyn et al. 2011), zooplankton composition (Antón-Pardo and Armegol 2012), cladoceran species richness (Boronat et al. 2001), hatching rates of rotifers (García-Roger et al. 2008) and other zooplankton groups (Valls et al. 2017). For some species, water conductivity acts as a trigger for hatching (Vanschoenwinkel et al. 2010) but increased salinity at the time of wetland filling may negatively impact the locally adapted hatching rate (Mabidi et al. 2018) and ultimately the persistence of the populations (Santangelo et al. 2014).

Similarly, whole plant community experiments in temporary coastal marshes showed that salinity increase impacted the germination, growth and seed production differentially for different plant species (Grillas et al. 1993b, Bonis et al. 1993).

As persistent egg and seed banks buffer the temporary wetland biota of drylands against the often-high natural (intra and inter-seasonal) variability, it may be assumed that their high resilience will also buffer against the effects of ongoing climate change. However, the already known climate change impacts on egg and seed banks, as detailed above, highlight their worsening status. Future research should therefore focus on the structure and functioning of egg and seed banks in a multi-stressor environment with more realistic scenarios with, for instance, mesocosm experiments ~~designs~~.

The role of trophic web maintenance

The aquatic communities of temporary wetlands are generally well adapted to climatic variation since ~~the inhabiting~~ organisms have the ability to live underwater for months and afterwards endure extreme conditions of drought during warm dry seasons (Sim et al. 2013). However, extreme events, such as extended heat waves or very high or low rainfall may, as already mentioned, induce stress to which existing adaptations of many organisms are ineffective and cause profound shifts in aquatic invertebrate biodiversity (Sim et al. 2013), plant species composition (Bagella and Caria 2013) and amphibian communities (Wassens et al. 2013).

The changes in species composition and abundance of single organismal groups at a particular trophic level induced by hydroperiod shifts may have cascading effects on the species composition and abundance of other organism groups via links in the food web (e.g. Pinero-Rodríguez et al. 2021). Different patterns between organisms having different dispersion modes and abilities are expected as a consequence of shifts in the hydroperiod of wetland (Sim et al. 2013, Kneitel 2016), leading to shifts in communities. For example, for active dispersers, optimal dispersal conditions (i.e., late spring) may become decoupled from the hydroperiod since they would occur when the wetlands are dry (Boix et al. 2016).

However, the natural heterogeneity of biota in temporary wetlands and the often-rapid ecological succession make it difficult to identify impacts of climate change on wetland biota and food web (Jones et al. 2013). A long-term study of 30 small artificial wetlands in Northumberland (UK) showed evidence of drought and inundation impacts on plants and invertebrates (Jones et al. 2013, Jeffries et al. 2016). They suggested that shifts in the length, intensity and frequency of the hydroperiod due to climate change will degrade biota, including a decline in the abundance of characteristic temporary wetland species whose adaptations may not be sufficient when faced with climate extremes (Jeffries et al. 2016).

~~As mentioned above, salinity affects the food web structure and therefore ecosystem functioning (Brucet et al. 2009, 2012, Jeppesen et al. 2015).~~ The structure of food webs changes from high complexity in mesosaline lakes, having multiple trophic levels with fish as top predators and diverse pelagic and littoral invertebrate assemblages (Hurlbert et al. 1986, Hammer 1993), to ~~more~~ simplified food webs in hypersaline lakes with amphipods as top predators and a shorter food web length (Lin et al. 2017, Golubkov et al. 2018, Jeppesen et al. 2020, Shadrin and Anufriieva 2020). Studies using stable isotope analysis suggest a declining food web complexity with increasing salinization (Cooper and Wissel 2012). Vidal et al. (2021) studied the community and food web structure in 24 lakes along a wide salinity gradient (i.e. subsaline to hypersaline lakes) in a semiarid region in north-west China using a stable isotope approach. They found a reduced number of taxa in all analysed communities and reduced complexity of the food web with increasing salinity.

The shifts in trophic structure and food web complexity with increasing salinity are, however, not simple, nor linear. For example, abrupt shifts can occur ~~when~~ specific salinity thresholds ~~are reached~~ (Williams 1998, Brucet et al. 2009, 2010, Lin et al. 2017, Jeppesen et al. 2020). Changes in size structure of fish have been observed as negative effect of increasing salinity (e.g. decrease in mean and maximum size; Sgarzi et al. 2020). When the salinity threshold for fish presence is passed, large-bodied invertebrate grazers released from fish predation become dominant. Another threshold is when the salinity becomes too high for large-bodied cladocerans (e.g. *Daphnia*), provoking a shift to dominance of anostraceans (*Artemia*). Although little information on the topic is available, abrupt salinity shifts are dependent on the temperature and trophic state of ~~the~~ lakes as well as ~~by~~ seasonal variations in salinity.

There is, therefore, an urgent need for follow-up studies, for coming up with ~~wider-reaching~~ conclusions, allowing implementation of adequate management measures at the watershed level (e.g. evidence based irrigation programmes) to prevent or mitigate the expected induced future changes in food web structure and biodiversity (Vidal et al., 2021).

Temporary wetlands as hotspots of biodiversity

Natural temporary wetlands are often hotspots of biodiversity due to their unique environmental features. They are characterized by hosting a unique set of species; hence in the Mediterranean region they are considered as priority habitats, to be conserved by the EU’s Habitats Directive (Zacharias and Zamparas 2010). Although these ecosystems play a key role for the maintenance of regional biological diversity, information on them is scarce or difficult to access. Studies carried out in Mediterranean temporary wetlands have shown high species richness (Waterkeyn et al. 2008, Rhazi et al. 2012, Gilbert et al. 2015, Blanco et al. 2020, Cunillera-Montcusí et al. under review), with the occurrence of endemic or rare species at regional scales (Blanco et al. 2019a, b, Marrone et al. 2020, Yılmaz et al. 2020). Moreover, these ecosystems also show high singularity (sensu Boix et al. 2008) and uniqueness ~~values~~, which, together with the high species richness, make them biodiversity hotspots.

Another relevant feature is connectivity, a key concept in species richness maintenance. High diatom diversity was reported in spatially grouped mountain wetlands (Blanco et al. 2020) supporting the hypothesis that species assemblages tend to be richer in areas that facilitate propagule dispersal and colonization, such as connected temporary wetlands (see also the section on egg and seed banks).

The typical inherent intra- and inter-annual fluctuations in the limnological features of wetlands drastically affect the seasonal variation in the structure and dynamics of the aquatic community, leading to increased heterogeneity and subsequently ~~the~~ biodiversity. As indicated in previous sections, studies have shown that ~~the~~ hydroperiod, time of flooding-desiccation, salinity, and trophic state are the main drivers determining species richness and community composition of plants and animals in Mediterranean wetlands (Alonso 1998, López-González et al. 1998, Brucet et al. 2009; Gilbert et al under review).

Regions of permanent waterbodies, river floodplains and eulittoral lake zones (i.e. the region between the maximum and minimum waterlines), that are wet only part of the time and are acting transiently as temporary wetlands, are gaining attention in biodiversity studies. In lakes with substantial water level fluctuations, the eulittoral zone tends to become overgrown by shore vegetation when dry. Then, with rising water levels, the vegetation is inundated and inhabited by macrophytes, invertebrates, fish and birds (Cummings et al. 2017). As the amplitude of water level fluctuations increases on a multi-annual scale, the stress on the aquatic biota inhabiting the eulittoral zone increases, converting it into a “desert” under extreme fluctuations, as is typical for reservoirs used for hydropower generation. The belt of water level fluctuations around lakes is understudied ~~for most large lakes~~. Given current global warming, it warrants much greater scientific interest.

Besides, the Intergovernmental Panel for Biodiversity and Ecosystem Services (IPBES 2018) listed invasive species as one of the five main drivers of biodiversity loss leading to transformation of natural ecosystems (Yılmaz et al. 2021). The importance of exotic/invasive species in shaping the ecological characteristics of temporary wetlands, including impacts from introduced domestic animals, such as cattle and goats, requires special attention, as wetlands often ~~are~~ hotspots for endemic species.

Resilience

Resilience is a critical property of ecosystems ~~that let to~~ return to their original state after disturbance or to absorb disturbances before shifting to another state, while remaining within ~~the~~ stable state~~s~~ (e.g. Holling 2001, IPCC 2014). Critical shifts between contrasting states in aquatic systems may be a consequence of persistent and small fluctuations (Scheffer et al. 2012). For instance, the severity and intensity of a drought can induce a transient state known as the "ghost state", where a clear and unstable state is maintained most of the time despite ~~the~~ high concentrations of nutrients (van Geest et al. 2007). On the other hand, regime shifts may lead to a strong degradation and eventually to an alternative stable state (Walker et al. 2004). This process occurs when ecosystems do not have sufficient ecological resilience to absorb disturbances and hence ~~to~~ remain within a given stable state (e.g. Peterson et al. 1998). According to IPCC (2014) the conditions that wetland biota ~~is~~ adapted to, will ~~suffer alterations~~, which may lead to a loss of resilience (Baho et al. 2017).

There is growing awareness among ecologists and managers of the need to assess resilience with different hypothe~~sis~~ frameworks ~~proposed (i.e the slow recovery;~~ Van de Leemput et al. 2018) and increasing ~~the amount of~~ studies on the effects of landscape spatial features on resilience (Allen et al. 2016). ~~Among the main aspects approached are~~ spatial regime description, disturbance intensity, ecological memory and functional connectivity (Allen et al. 2016). As a result, the concept of resilience has changed over time and currently incorporates multidisciplinary perspectives.

Studies on functional traits and adaptive strategies have been widely used to predict the future state of temporary waters (Bazzanti et al. 2009, Schmera et al. 2017). Here, environmental filters determine the selection of traits and strategies, which in turn influence the process and functioning of aquatic ecosystems. Currently, the enhanced magnitude of drought has changed the water regime of temporary wetlands, acting as a powerful filter and increasing the abundance of the most tolerant species in adverse conditions, such as salt-tolerant species (Castillo et al. 2018, Vidal et al. 2021). For example, results from macroinvertebrate studies have shown high sensitivity of gatherers and filterers to salinity (Castillo et al. 2018). For the most part, recovery is rapid and favoured by species characteristics, indicating high resilience of aquatic communities to disturbances (Fritz and Dodds 2004). To face the typical disturbance regime~~n~~ in temporary wetlands, the main characteristics of the species reported were widespread dispersal, high abundances and high growth rates ~~are among the most important~~ (Williams 2006). The evolutionary process selects traits and strategies that are adapted to seasonal drying and flooding over time, but the speed of current changes~~,~~ can limit this adaptive capacity.

A timely and urgent goal for wetland scientists is to understand the main mechanisms associated with ~~the~~ disturbance by extreme drought~~ and~~ reduced resilience and ~~how this affects~~ aquatic biodiversity and ecosystem functioning in ~~unpredictable~~ scenarios. ~~T~~o reconcile the concept of ecological resilience with natural disturbances and human impacts (Angeler 2021) ~~in order~~ to establish more efficient management strategies~~ is also an urgent research need~~. ~~The connections among the thematic blocks placed on the table in the workshop, typical of complex systems, should move us to search onto~~ ~~e~~mergent behaviours and ~~proprieties~~ in order to anticipate future ~~scenarios~~ and ~~reach~~ solutions. Research networks operating at different levels (form local to international level) and the collaboration with all the stakeholders would promote the sharing of knowledge and ~~the solving problems actions to~~ enhance protection of these endangered aquatic systems.

Post COVID-19 challenges

During the workshop it became evident that the SARS-CoV-2 was spreading, developing into a pandemic. The effects on human health, but also on the world economy will undoubtedly slow the achievement of the Sustainable Development Goals (SDGs), probably entailing a need for further prioritisation of specific goals within individual countries or regions (Naidoo and Fisher 2020). This is reasonable and manageable, but actions in response to the environmental crisis cannot be delayed, as shown by the urgency of the situation for wetlands globally, as recently outlined in the Second Warning to Humanity (Finlayson et al. 2019) and Global Wetland Outlook (Ramsar Convention on Wetlands 2018). The measures introduced to control the pandemic, and their consequences and impact on aquatic ecosystems, are a topic that needs immediate attention (El-Nahhal and El-Nahhal 2020). The gap between the identification of the need for emergency actions and the time needed for the necessary decisions to be made and subsequent actions taken is a further threat to wetlands. Hence the importance of this special issue as a step towards levering greater efforts to ensure their protection based on scientific evidence.

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Figure caption.

Figure 1. Connexions among drivers, thematic blocks and the solutions discussed in the workshop ~~with~~ (-) negative and (+) positive impacts.

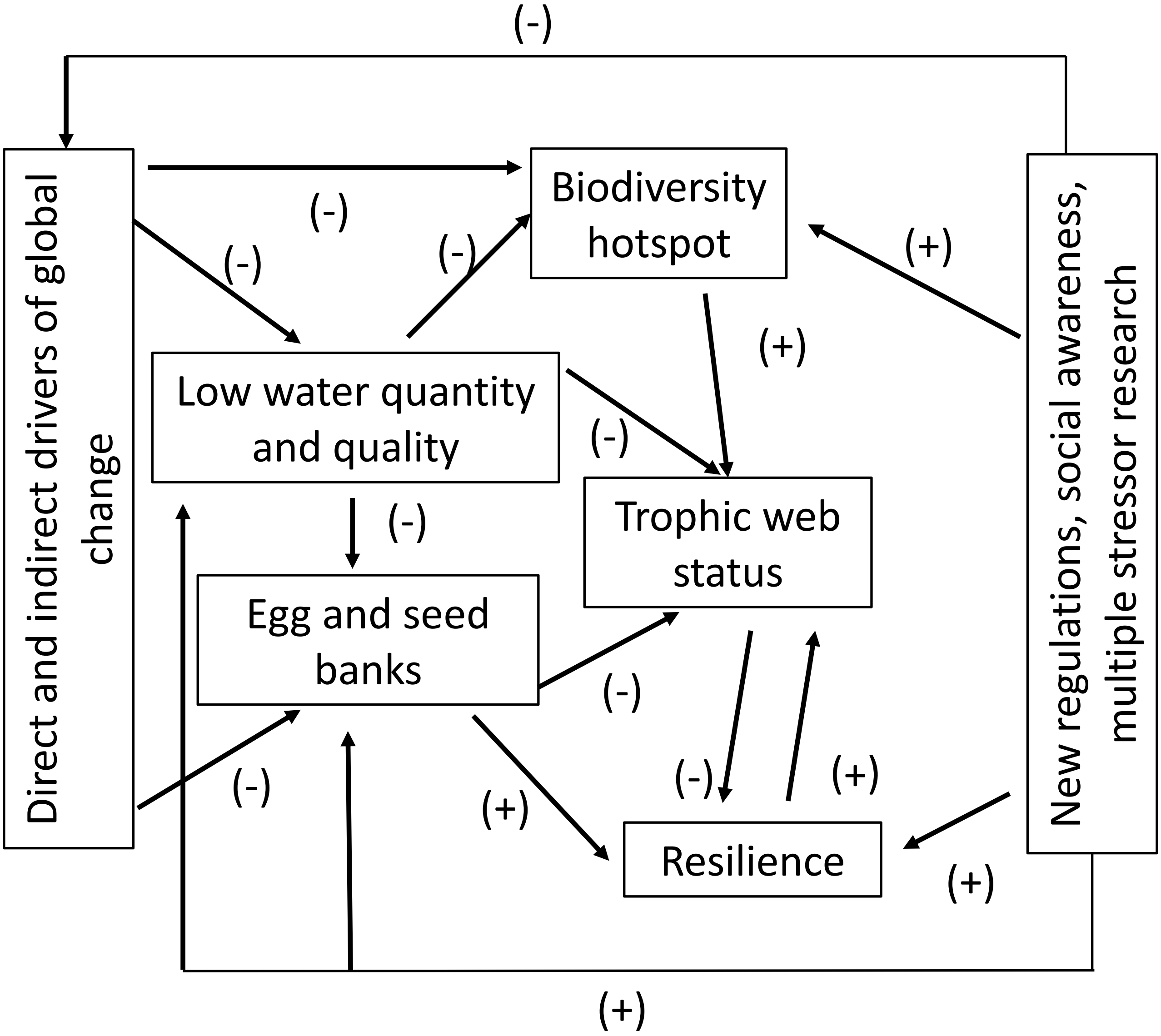
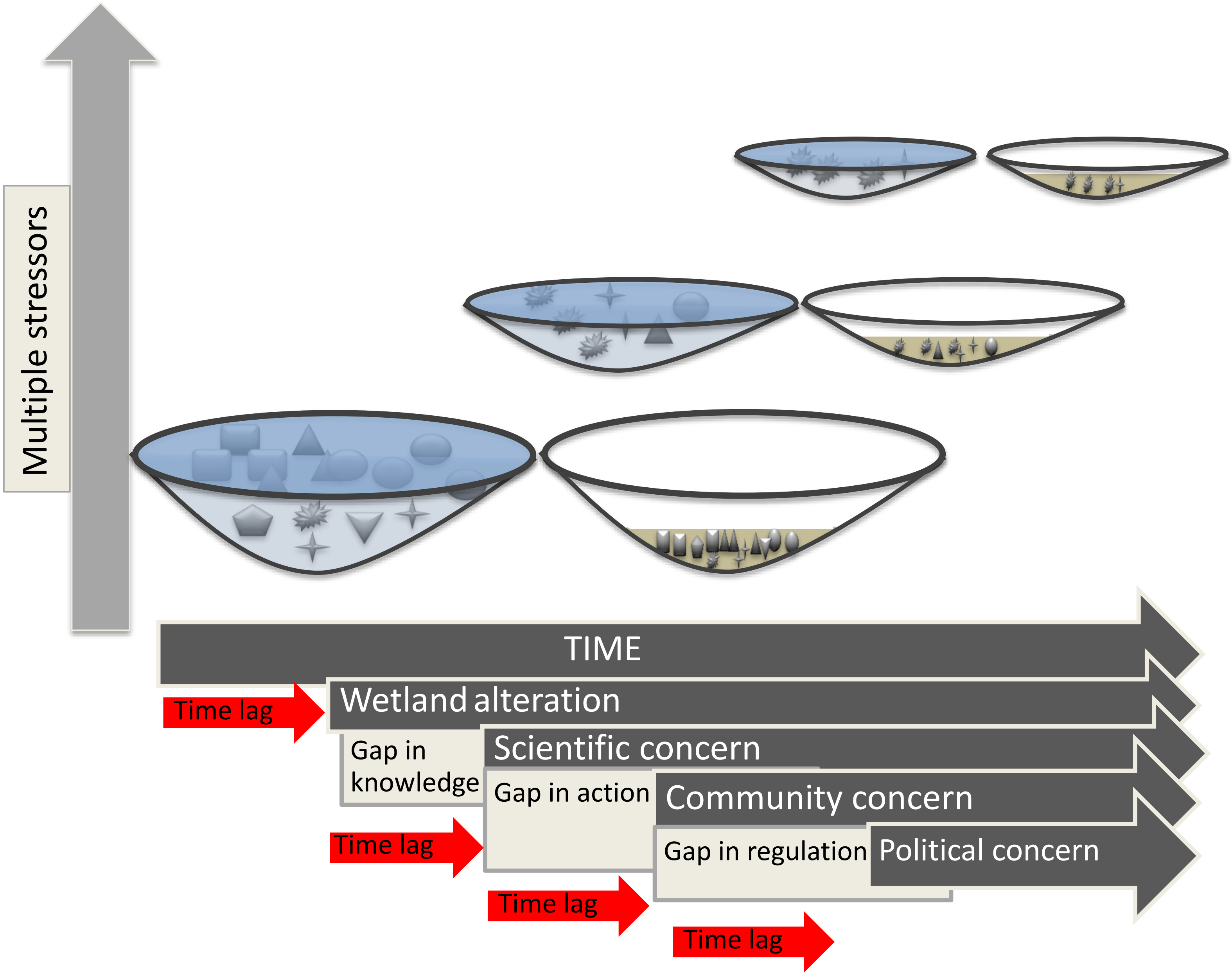


Figure 1. Connexions among drivers, thematic blocks and the solutions discussed in the workshop with (-) negative and (+) positive impacts.

Graphical abstract



Multiple stressors

TIME

Time lag

Wetland alteration

Gap in knowledge

Scientific concern

Time lag

Gap in action

Community concern

Time lag

Gap in regulation

Political concern

Time lag

Graphical abstract caption.

Schematic representation on wetlands threats and challenges. Wetlands' wet and dry phases affected by multiple stressors over time. The emergency in protecting these ecosystems on faces the gaps in knowledge, in actions and in effective regulations.