LIFE Prespa Waterbirds

Bird conservation in Lesser Prespa Lake: benefiting local communities and building a climate change resilient ecosystem

Action A.6: Assessment of habitat vulnerability to climate change to establish "climate change proof" wetland vegetation management

PRESPA
WATERBIRDS

DELIVERABLE 1

Final report of the assessment of habitat vulnerability to climate change

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Contents

1. Introduction

This report is the first deliverable of action A.6, entitled «Assessment of habitat vulnerability to climate change to establish "climate change proof" wetland vegetation management». This action is headed by the National Observatory of Athens (NOA) and runs from September 2016 until December 2017.

This assessment will directly inform wetland vegetation dynamics (Action A1), management guidelines (Action A2), and stream mouth restoration (Action A3) thus making sure that the relevant management actions (C1, C2 & C3) are "climate proof" – that is, sustainable and effective under future climate change scenarios.

1.1 Action A.6: Aim and threats addressed

Action A6 aims to assess the impact of climate change on the alluvial shorelines of Lake Lesser Prespa. Reedbeds along this shoreline offer crucial bird nesting sites, whereas seasonally flooded "wet meadows" that are located landward of the reed-belt constitute important fish spawning grounds and bird foraging areas. Two of the major threats faced by the target bird species in the study area concern (i) food constraints due to the limited "wet meadow" foraging areas available for target species and (ii) low breeding output due to reedbed wildfires destroying nests.

1.2 Climate change: impact on threats

Both aforementioned threats, i.e. [i] food constraints to waterbirds due to limited "wet-meadow" availability and [ii] reedbed fires destroying nests, are strongly influenced by climate.

Catchment precipitation and lake surface evaporation are the main drivers of lake level fluctuations. A sluice sets maximum water levels of Lesser Prespa Lake; minimum water levels are to some extent regulated. Droughts strongly impact upon lakeshore habitats as they decrease seasonal lake level variability and force a drop in water level, occasionally to below the base of the sluice. Under such conditions, there is limited or no seasonal flooding of the lake margin and wet meadow environments, while the shoreline advances into the lake - often to within the reedbeds - and thus the aerial extent of the available open shallow foraging environments and fish-spawning grounds decreases. A significant part of the current nesting sites is also very vulnerable to fire under low lake levels and drought conditions as these facilitate widespread fire-access to desiccated reedbeds and increase the fire frequency / magnitude. Projected future climate change will amplify these threats as periods with low lake levels, droughts and air temperature (and thus lake evaporation / -temperature) will increase.

1.3 Report Outline

This report contains the first vulnerability assessment of crucial wading-bird shoreline habitats around Lesser Prespa Lake to climate change. The assessment outcomes are presented as follows:

Section 2 explains the approach taken by this study to focus on analogues and threshold values to assess the future impacts on shoreline habitats. It presents baseline information regarding lake level behavior and relevant hydro-climatic parameters.

Section 3 uses these baseline data to establish precipitation- and drought-based thresholds that correspond with a significant drop in water level of Lake Lesser Presa. Furthermore, this section links maximum air temperatures to lake temperatures. These thresholds and temperature correlations are crucial for future impact analyses.

Section 4 evaluates changes in lake-marginal environments that are driven by observed hydro-climatic (chapter 2) and land-use changes. Fire-access to reedbeds is also assessed, drawing upon observational data.

Section 5 presents future catchment-specific precipitation, temperature, drought and evaporation projections based on the latest high-resolution climate model.

Section 6 explores the impacts of the projected future changes in catchment climate on lake level lowstands, lake temperature and shoreline habitats.

Section 7 shows and interprets the results from the FWI analyses and sheds light upon future fire behaviour.

Final section 8 uses the impact projections (sections 6-7) to feed site-specific vulnerability assessments of available fish spawning grounds, bird nesting- and foraging sites under future climate scenarios. Furthermore, crucial management guidelines are formulated regarding the required altitudinal range of future open shallows areas and the location of fire-corridors protecting reedbeds.

Additionally, Annex 1 assesses the impact of projected changes on agricultural (bean) cultivation in the basin. This text is written in answer to the request from the local agricultural community to assess the impact of future climate change on the key cash-crop that is currently grown in the alluvial plains surrounding Lesser Prespa Lake.

2. Lake level fluctuations: baseline conditions

The current study strongly relies on modern analogues and threshold values to assess the future impacts on lake level and shoreline habitats. This is the most reliable and robust approach to assess the impact of projected future changes in catchment climate due to the lack of discharge, water storage/abstraction and groundwater-flow data which make reliable water-balance modelling impossible (van der Schriek and Giannakopouos 2017). Establishing base-line conditions regarding lake level behavior under the observed hydro-climate is an essential prerequisite for such an approach.

This section presents baseline information lake level fluctuations of the Prespa Lakes. The hydro-geological and hydro-climatic conditions of the Prespa catchment are briefly described and main data-sources are given. Particular attention is given to human-induced hydrological changes affecting Lake Lesser Prespa, in order to facilitate the interpretation of lake level fluctuations. The remaining part of the chapter focusses on the description and interpretation of the water level behavior of Lake Lesser Prespa.

2.1 Prespa catchment

The internally draining Prespa Lakes (40º51’53”N, 21º03’08”E) occupy a ~1300 km^2 catchment area (Fig. 2.1) covering Albania, Greece and the Former Yugoslav Republic of Macedonia (FYROM). The lake basin is surrounded by steep mountains rising to over 2000 m. Mountains to the north and east of the basin are composed of impermeable granite and crystalline-metamorphic rocks. These rocks underlie the entire catchment, including the dolomitic limestone mountains to the west and south of the basin. Narrow alluvial plains and -fans border the lake to the north and east, containing small and mainly unconfined gravel aquifers that are recharged by precipitation (Kosmas et al. 1997). The lake is only in direct contact with limestone along its central to southwestern shore where this substrate continues at depth due to down-faulting of the southern part of the horst that separates the Prespa Lakes from ~150 m lower Lake Ohrid to the northwest (Popovska and Bonacci 2007). There is significant underground karst outflow from the SW section of Lake Greater Prespa to springs in the Ohrid Lake Basin (Amataj et al. 2007).

The basin’s climate is continental Mediterranean (FAO/UNESCO 1963), with warm dry summers (mean July: 21° C) and rather cold humid winters (mean Jan: 1° C) giving a mean annual temperature of 11° C. Average annual precipitation at lake level reached 763 mm and lake evaporation 833 mm (open-pan evaporation: 1041 mm) over the period 1951-2004. Annual precipitation is likely well over 1200 mm in the mountains (Hollis and Stevenson 1997; Popovska and Bonacci 2007). The wet season (from October to April) receives 73% of the total annual precipitation with significant snowfall in the mountains. The moisture balance (precipitation minus evaporation) is only positive from October until the end of March. Fluvial discharge increases from November to peak in April or May due to snowmelt, while the other months are characterised by low discharges. The annual water level cycles of the Prespa Lakes mirror discharge. Lake Greater Prespa has peak levels in May or June and lowest levels in October or November (seasonal variability: ~0.5 m). Seasonal peak lake level lags ~5-6 months behind peak precipitation due to transfer delays caused by snow-melt

(Hollis and Stevenson 1997). Superimposed on this annual water level cycle are (multi-) decadal fluctuations caused by particularly wet or dry periods. Water level cycles of Lake Lesser Prespa are detailed below (section 2.5).

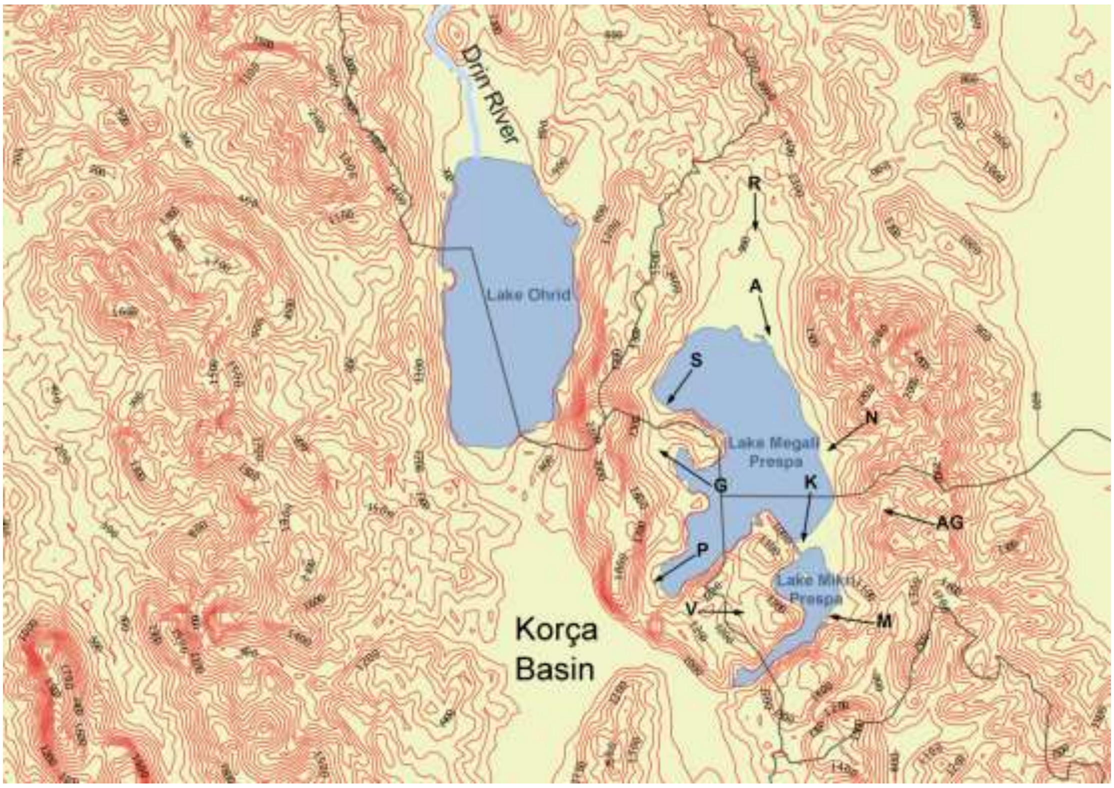


Figure 2.1The Prespa Lakes and their catchment area. Letters correspond to local meteorological stations (locations mentioned in the text are: Koula Isthmus (K), Aghios Germanos (AG) stream)

Lakes Lesser and Greater Prespa are connected by a channel through the narrow alluvial isthmus of Koula (Fig. 2.1, K). The level of Lesser Prespa Lake has been stabilised since 1969 by a weir in the channel and fluctuates around 850 m (surface area: ~52 km^2, volume: ~330 hm^3, max. depth: ~8 m, residence time: 4-7 yr). Since 2004, a new sluice has been in operation which regulates water level fluctuations of Lesser Prespa Lake to some extent, mainly to avoid exceeding clearly defined upper and lower water level boundaries (Parisopoulos *et al*. 2007). Greater Prespa Lake currently fluctuates around 845 m (surface area: ~254 km^2, volume: ~2990 hm^3, max. depth: ~54 m, residence time: 11-17 yr). The lakes are currently mesotrophic and direct precipitation accounts for 35-45% the total water input, while the remainder is contributed by fluvial discharge and negligible groundwater inflow (Matzinger et al. 2006). The lakes discharge solutes via underground karst drainage channels that account for 46% of the total water loss. Thus their waters remain fresh despite evaporation, which explains 54% of the total water loss, and the absence of surface outflow.

2.2 Data

Observational data used in this report were mainly obtained from the "Society for the Protection of Prespa", which possesses all major meteorological and hydrological records spanning 1951-2004 in the Prespa catchment from the three lake-sharing countries (GFA Consulting 2005). Principal records include: (i) monthly stage heights (1951-2004) of Lake Greater Prespa from the Hydrological Institute of Skopje (FYROM; the only lake record subjected to quality control) and of Lake Lesser Prespa (1969-2016) from the local Koula station; (ii) a single precipitation record created from monthly precipitation series (1951-2004) from seven stations (containing basic equipment) located adjacent to the lakes at ~860 m, using the surface integration method (Direct Weighted Averages and Thiessen Polygons; cf. Burrough and McDonnell 1998); and (iii) monthly evaporation based on a 23-year record with a standard Class A-Pan instrument (Koula station; Greece) and extended using the Penman method to cover the entire 1951-2004 observation period. Class-A-Pan evaporations tend to overestimate lake evaporation; therefore a Pan-coefficient of 0.8 was introduced to convert the 54-year Pan-Evaporation series into a Lake-Evaporation series. Additionally, temperature and precipitation data for Lake Lesser Prepa were extracted from the E-OBS gridded dataset, which contains series of daily observations from meteorological stations throughout Europe and the Mediterranean (Haylock et al. 2008).

2.3 Lake level fluctuations of the Prespa Lakes

The annual water level regime of the Prespa Lakes reflects its complex geological setting and is a function of: (i) local fluvial and groundwater input, (ii) direct lake precipitation, (iii) lake surface evaporation, (iv) water abstraction for irrigation, and (v) karst outflow (Matzinger et al. 2006; Popovska and Bonacci 2007). Factors (i-iii) reflect the average climatic conditions of the catchment area, as all fluvial and groundwater input is generated by precipitation within the confines of the steep-rimmed lake catchment. Water is directly abstracted from the lake, and from wells accessing shallow aquifers, since the 1950s. Both types of abstraction affect lake level and explain a large part of the observed long-term drop in the level of Lake Greater Prespa since 1951. Furthermore, karst outflow is relatively stable over the observed range (852-842 m) of lake level variability (van der Schriek and Giannakopoulos 2017). The internally draining lakes mainly adjust to sustained inflow changes through amending total surface area and thus lake-surface evaporation; adjustments of karstic outflow rates in response to lake level variability are inferred to be minor.

Water level fluctuations of Lakes Lesser and Greater Prespa (Figs. 2.2 and 2.3) cannot be modelled reliably with Lake Water Balance models, as too many essential parameters (i.e. factors i, iv and v above) are unknown. However, analyses based on empirical data and linear correlation work well. Annual lake volumetric change is strongly correlated to the "wet season" precipitation variability (from October $_{\text{year1}}$ to end March $_{\text{year2}}$) of the hydrological year that runs from October$_{\text{year1}}$ to September$_{\text{year2}}$ (van der Schriek and Giannakopoulos 2017). Prior to 1976, water level fluctuations of Lakes Lesser and Greater Prespa moved approximately in tandem. Since 1976, Lake Lesser Prespa is perched above Lake Greater Prespa as the latter's water level fell below the base of the weir in the channel connecting the two lakes.

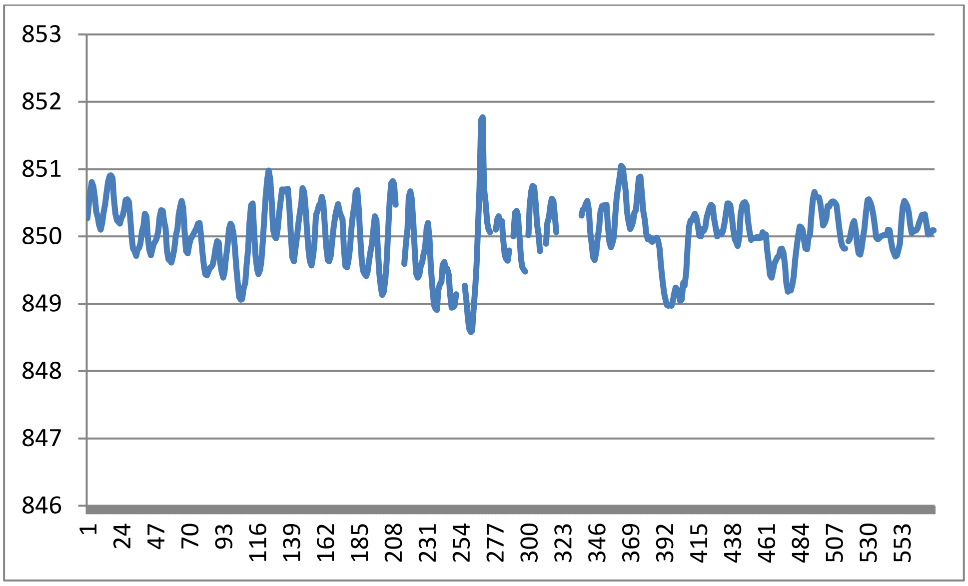


Figure 2.2 Lesser Prespa Lake level fluctuations in m above sea level (monthly; Feb 1969 – Dec 2016)

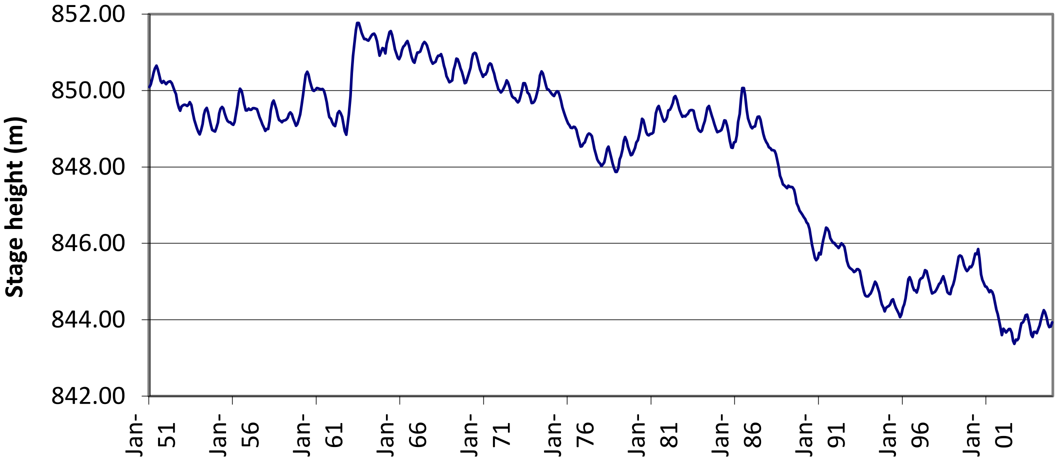


Figure 2.3 Greater Prespa Lake level fluctuations (monthly; Jan 1951 – Dec 2004)

Precipitation drives (multi-)annual lake level variability. Specifically, large lake level rises and falls have been linked to regional wet winter-spring periods (e.g. 1962-63) and multi-annual drought events (e.g. 1974-78 and 1987-95), respectively (Livada and Assimakopoulos 2007, Mavromatis 2011). However, there has been no statistically significant change in Prespa catchment precipitation over the period of detailed observations (1951-2004) according to van der Schriek and Giannakopoulos (2017). Detailed water level and precipitation data are available for Greater Prespa Lake. When wet season precipitation is <500 mm, there is a fall in lake level from October $_{\text{year1}}$ to October $_{\text{year2}}$. If the wet season precipitation <405 mm ***and*** annual precipitation <680mm, there is a significant annual fall in lake level (of more than -0.65 m) and there is no wet season lake level peak at all (severe drought; continuous falling water level throughout the year).

2.4 Human-induced changes in the hydrology of Lake Lesser Prespa

The relation between lake level variability and precipitation of Lesser Prespa Lake is more difficult to evaluate after 1976, when the lake became perched above Greater Prespa Lake and its hydrology strongly affected by human-induced changes such as water abstraction, water storage and sluice operation. This section summarises the main human-induced changes in the hydrology of Lake Lesser Prespa over the period 1951-2016, in order to help interpretation of the lake level movements in the following section (2.5).

In 1969, a concrete channel and culvert with a spill crest at 849.60 m replaced the "weedy shallow channel" across the Koula isthmus (Fig. 2.1) that connected Lakes Lesser and Greater Prespa. A sluice was constructed in 1985 in the concrete channel, which was destroyed around 1992; there are no data on its operation. A new sluice-system was constructed in 2004 and up to the present this sluice strongly controls outflow. The system consists of four outflows: two outflows at 849.58 m and two outflows at 849.98 m. The management policy is to keep lake level maxima at 850.6 m (850.8 m in exceptional circumstances) and the wet meadows flooded during fish spawning season around the end of April, meaning that water level during this month should be at 850.4-850.2 m (Parisopoulos *et al*. 2007).

From 1969 until the end of 1973 the water level of Lake Lesser Prespa did not fall below the sill depth (849.60 m). Since 1976, Lake Lesser Prespa has been perched above Lake Greater Prespa. However, the height difference between the two lakes was only up to 2 m up to end 1987. The dramatic drop in water level of Lake Greater Prespa between 1987 and 1995 increased the height difference between the two water surfaces. Since 1995, this difference fluctuates between 5 to 7 m. The difference in water level between the two lakes created a groundwater flow from Lesser to Greater Prespa Lake through the alluvial isthmus. Falling levels of Lake Megali Prespa increased the hydraulic gradient significantly and thus this underground flow, which is estimated at 12.6-17.3 x 10^6 m^3/year since 1995 (Parisopoulos *et al*. 2007).

Free flowing water abstraction during the dry season took place from the SW (Albania) extremity of Lesser Prespa Lake through an artificial channel from 1953 up until 1975. The maximum amount of water annually abstracted has been estimated at 20 x 10^6 m^3. Water storage and abstraction have strongly influenced seasonal water level variability of Lake Lesser Prespa since the connection with the Devolli River (SW Albania) was realized in 1976. The channel, with a dam/sluice system, allowed abstraction from the Devolli River in the wet season and storage in Lesser Prespa Lake. Water flow in the channel was reversed in the dry season to abstract water from the lake. This entire system was abandoned in 2001. There are only rough estimates of the amount of water involved. Between 1976 and 1990 there was a maximum inflow of 40 x 10^6 m^3 and a maximum outflow of 45 x 10^6 m^3. However, the volumes involved decreased over the years due to sedimentation problems and low efficiency of the hydraulic structure. From 1990 to the final year of operation in 2000, annual maximum in-/outflow decreased from 20 x 10^6 m^3 to 4 x 10^6 m^3 (GFA Consulting 2005).

Finally, water abstraction from the Greek part of Lesser Prespa Lake for intensive bean cultivation increased gradually from its start in 1976. The following estimates are available: 1976, 1 x 10^6 m^3; 1977-1984, 2 x 10^6 m^3; 1984-present, 6-8 x 10^6 m^3. Overall, the effect of water abstraction during the dry season must decrease peak lake level. This decrease must have been particularly pronounced when the Devolli diversion was fully operational from 1976-1990. During the same period, water put into Lesser Prespa Lake during autumn-winter decreased the seasonal fall of lake level. However, part of this extra water ended up in Greater Prespa Lake due to the existence of the Koula channel connecting the Prespa Lakes.

2.5 Water level fluctuations of Lesser Prespa Lake

This section presents the upper and lower limits of the water level of Lesser Prespa Lake, as well as the changes in seasonal fluctuations based on observations. The observational record of Lesser Prespa Lake water level fluctuations covers the years from February 1969 until December 2016, albeit with a few gaps (Fig. 2.2). The principal aim of this section is to distinguish and define "natural" lake level variability, in order to inform the water level management regime. To address this aim, observed lake level fluctuations are described and interpreted.

Five periods can be defined (Table 2.1), based on hydrological changes described in section 2.4.

[1] 1969-1976. The Prespa Lakes are fully communicating, although the water level of Lesser Prespa Lake falls from 1973 onwards occasionally below the depth of the sill (at 849.6 m) in the Koula channel. Lake level varied between 851 m (maximum) and 849.4 m (minimum). The average annual fall in lake level is -0.75 m, while the average rise in lake level over the hydroyear (running from October $_{year1}$ to September $_{year2}$) is 0.67 m. Peak lake levels occur from the end of April to the beginning of June, with the majority occurring in May. Seasonal lake level lows take place from the end of September to the beginning of December.

[2] 1976-1986. The lake is perched by up to 2 m above Greater Prespa Lake, initiating groundwater flow through the coarse-grained isthmus. The Devolli diversion is established and large water volumes are consequently stored (winter-spring) and abstracted (summer-autumn). The sluice installed in 1985 in the Koula Channel is likely not closed in 1986 due to high lake levels.

Over this period, lake level varied between 851 m (maximum) and 849 m (minimum). The average annual fall in lake level is -1.13 m, while the average rise in lake level over the hydroyear (running from October $_{year1}$ to September $_{year2}$) is 1.20 m. Peak lake levels occur from February to mid-May, with the majority occurring from mid-March to mid-May. Seasonal lake level lows take place from the end of August to the end of September.

YEAR	MAX (m)	Date	MIN (m)	Date	Annual water level fall (m)	Hydro-annual rise MIN year$_1$ to MAX year$_2$ (m)
1969	850,81	20/5	850,08	26/11	-0,73	
1970	850,93	24/5	850,18	18/12	-0,75	0,85
1971	850,56	21/4	849,71	17/11	-0,85	0,38
1972	850,34	12/5	849,69	25/9	-0,65	0,63
1973	850,41	26/4	849,58	4/11	-0,83	0,72
1974	850,56	1/6	849,75	21/9	-0,81	0,98
1975	850,25	23/5	849,41	2/10	-0,84	0,50
1976	849,94	13/6	849,39	11/10	-0,55	0,53
1977	850,19	14/3	849,01	18/9	-1,18	0,80
1978	850,53	9/5	849,43	6/9	-1,10	1,52
1979	850,97	27/4	849,97	25/8	-1,00	1,54
1980	850,73	2/2	849,58	25/9	-1,15	0,76
1981	850,73	15/4	849,57	10/9	-1,16	1,15
1982	850,59	30/4	849,57	8/9	-1,02	1,02
1983	850,49	31/3	849,53	12/9	-0,96	0,92
1984	850,73	13/4	849,41	16/9	-1,32	1,20
1985	850,34	13/5	849,10	20/9	-1,24	0,93
1986	850,83	28/5	N/A	N/A	N/A	1,73
1987	850,67	18/4	849,38	14/9	-1,29	N/A
1988	850,20	12/4	848,90	13/9	-1,30	0,82
1989	849,63	22/3	848,89	20/9	-0,74	0,73
1990	N/A	N/A	848,56	15/9	N/A	N/A
1991	851,12	31/5	850,02	4/11	-1,10	2,56
1992	850,33	29/4	849,63	29/9	-0,70	0,31
1993	850,38	15/4	849,48	8/9	-0,90	0,75
1994	850,78	18/3	849,78	20/9	-1,00	1,30
1995	850,58	22/4	N/A	N/A	N/A	0,80
1996	N/A	N/A	N/A	N/A	N/A	N/A
1997	850,53	6/4	849,63	22/9	-0,90	N/A
1998	850,49	13/3	849,78	2/9	-0,71	0,86
1999	851,08	7/4	850,10	6/9	-0,98	1,30
2000	850,92	10/4	849,92	22/9	-1,00	0,82
2001	849,98	3/1	848,97	24/10	-1,01	0,06
2002	849,24	22/4	848,99	12/8	-0,25	0,27
2003	850,35	22/3	849,95	19/9	-0,40	1,36
2004	850,48	28/4	849,98	3/9	-0,50	0,53
2005	850,50	30/3	849,86	9/9	-0,64	0,52
2006	850,54	13/3	849,45	11/9	-1,09	0,68
2007	850,04	29/1	849,35	12/9	-0,69	0,59
2008	849,48	15/4	849,17	2/9	-0,31	0,13
2009	850,17	8/5	849,78	9/9	-0,39	1,00
2010	850,67	22/2	850,12	8/9	-0,55	0,89
2011	850,54	28/2	849,80	10/10	-0,74	0,42
2012	850,25	19/3	849,71	29/8	-0,54	0,45

2013	850,59	4/3	849,92	20/9	-0,67	0,88
2014	850,03	1/1	849,69	25/8	-0,34	0,11
2015	850,54	18/3	850,07	7/9	-0,47	0,85
2016	850,35	15/3	849,98	25/8	-0,37	0,28

Table 2.1 Lesser Prespa Lake: min and max water levels (1969-2016)

Compared to the first period, seasonal lake level peaks and lows are (much) earlier in season, while lake level fluctuations are much larger. These changes are likely related to (i) the absence of the dampening effect of Greater Prespa Lake, as Lesser Prespa Lake is now perched, and (ii) the amplifying effect on seasonal lake level fluctuations of water storage/abstraction associated with the Devolli connection.

[3] 1987-1992. Over this period, there is a large drop in water level of Greater Prespa Lake due to a long drought (van der Schriek and Giannakopoulos 2017). A significant increase in the underground flow through the isthmus (from Lesser to Greater Prespa Lake) must have been established. Also, a sluice in the Koula channel was likely operational and closed over this period. Finally, Greek water abstraction becomes more intensive, while the use of the Devolli diversion decreases.

From 1987 to 1992, lake level varied between 851 m (maximum) and 848.5 m (minimum). The average annual fall in lake level is -1.03 m, while the average rise in lake level over the hydroyear (running from October $_{\text{year1}}$ to September $_{\text{year2}}$) is also 1.03 m. Peak lake levels occur from mid-March to May, with the majority in April. Seasonal lake level lows take place in September, and once in the beginning of November. The pattern of lake level variability is very similar to the second period and the climatic/hydrological boundary conditions are comparable.

[4] 1992-2004. The sluice in the Koula channel is no longer operating during this period. The water level of Greater Prespa Lake is 5-7 m lower, thus continuing the significant groundwater flow through the isthmus. The water volumes associated with storage/abstraction through the Devolli diversion decrease significantly before ending in 2002.

From 1987 to 1992, lake level varied between 851 m (maximum) and 849 m (minimum). The average annual fall in lake level is -0.77 m, while the average rise in lake level over the hydroyear (running from October $_{\text{year1}}$ to September $_{\text{year2}}$) is also 0.78 m. Peak lake levels occur from mid-March to April, while 2001 shows no seasonal peak at all. Seasonal lake level lows take place from mid-August until mid-October, with the majority in September. Seasonal lake level fluctuations have decreased compared to the second and third period, and are more similar to the start of the observational record (first period: 1969-1976). This decrease is probably related to the closure of the Devolli diversion.

[5] 2005-2016. Water level fluctuations of Lesser Prespa Lake are strongly controlled by a sluice-system. The sluice was entirely closed (no surface outflow) between the following dates: 1/9/2005-10/02/2006, 18/09/2006-10/02/2010, 07/03/2012-11/02/2013, 15/07/2013-11/02/2015 and 22/07/2015-16/12/2016. Specifically, surface outflow was stopped [a] if lake level fell below 849.90-850 m during seasonal lake lowstands (Sept-Feb), and [b] if peak lake level (May-July) fell below 850,30 m. Sluices were opened when lake level rose (Feb-Apr) above 850.20-850.50 m.

Over the period from 2005 to 2016, lake level varied between 850.70 m (maximum) and 849.20 m (minimum). However, water level fluctuated mostly between 850.50-849.75 m. Lake level fluctuations were strongly influenced by sluice management; only during two years (2010-2011) there was continuous (although controlled) surface outflow. The average annual fall in lake level is -0.57 m, while the average rise in lake level over the hydroyear (running from October $_{\text{year1}}$ to September $_{\text{year2}}$) is also 0.57 m. Peak lake levels occur from end-February to mid-April, with the majority in March. During 2007 and 2014 there was no seasonal peak at all. Seasonal lake level lows take place from end-August until begin-October, with the majority in September. Average seasonal lake level fluctuations are the lowest on record. Furthermore, the occurrence of peak lake levels appears to shift to earlier in the season. These changes are likely related to sluice operation.

2.5.1 Inferences about "natural" water level fluctuations

Linear correlation between lake level and precipitation cannot be used for Lesser Prespa Lake. Seasonal water fluctuations here are strongly influenced by variable water abstraction/storage and groundwater flow changes over the observation period. None of these parameters is properly quantified. However, the existing linear correlation (Fig. 2.4) between water volumetric change of Greater Prespa Lake and precipitation may be used to analyse Lesser Prespa Lake prior to the separation of the lakes in 1976.

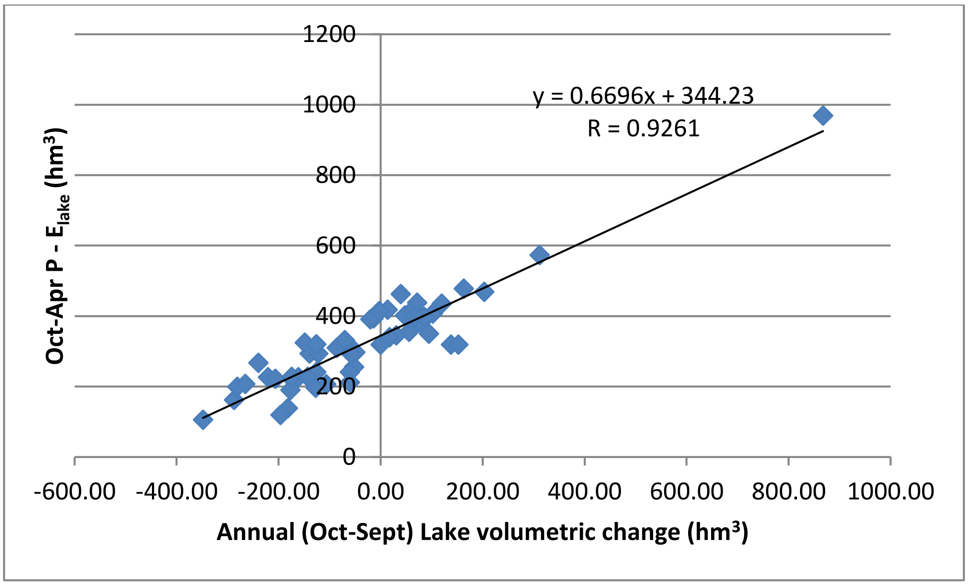


Figure 2.4 Linear correlation of water volumetric change (Greater Prespa Lake) and wet season precipitation

The situation prior to 1976 can be taken to represent the most “natural” conditions. The Prespa Lakes were fully communication up to this date, while large-scale water storage and abstraction schemes were not yet operating. Average seasonal water level fluctuations of Lesser Prespa Lake ranged from 0.65 m to 0.75 m. Longer-term (multi-annual) water level fluctuations mirrored those of Greater Prespa Lake. From the start of the water level observations of Lesser Prepa Lake in 1969 until 1976, lake level fluctuated between 851 and 849 m. On longer timescales, from 1917 until 1976 based on the Greater Prespa Lake record, lake level experienced much larger fluctuations between 847.50 to 852 m.

The sluice-system that operates since 2005 in the Koula outflow channel strongly dampens both seasonal water level fluctuations as well as long-term lake level variability. However, lake level lowstands below the base of the sluice at 849.58 m occasionally occur; consequently, these lowstands cannot be influenced by sluice operation. Following chapter 3 focuses on such lake level lowstands, which may become more frequent in the future, and links their occurrence to precipitation and drought-based threshold values.

3 Lake lowstand precipitation thresholds and surface temperature

Maximum water levels of Lesser Prespa Lake are strongly regulated (at 850.60 m; section 2.4). Wet periods therefore do not lead to significant water level or shoreline (habitat) changes. However, water levels may fall substantially below the base of the sluice (849.58 m). Such lake lowstands do directly affect shoreline habitats (as discussed in the next section 4).

Here we aim to set precipitation based thresholds, and relate these to the SPI drought-index, indicating the (i) occurrence of very low lake levels (i.e. when levels fall to below the base of the sluice), and (ii) closure of the sluice and reduced lake level variability. Furthermore, this section links maximum air temperatures to lake surface temperatures. Lake temperature is a crucial parameter for chemical-biological processes taking place in the lake, including fish spawning and algae blooms.

The thresholds and temperature correlations of this section are key for determining future impact analyses (sections 6 and 7; annex 1).

3.1 Key lake level analogues and stage-height indicators

A set of key lake level analogues has been defined on the basis of the available water level data of Lesser Prespa Lake (section 2.5). These analogues are linked to absolute precipitation thresholds and drought-indexes, respectively, in the subsequent paragraphs.

The following four lake level analogues have been demarcated:

[A] Significant lake level lowstands are defined as hydrological years (October $_{\text{year1}}$ to September $_{\text{year2}}$) when water levels are <850 m for 12 months, while water levels are below 896,6 m (the base of the sluice) for 5 months and more. Under such conditions the sluice would be closed for the entire hydro-year.

[B] Extreme lake level lowstands, when water level is at or below 849 m. Such lake levels may become more frequent in the future; it is therefore of the utmost importance to identify the conditions under which such lowstands occur.

[C] Lake level lowstands, when water levels are below the 850 m stage-height for 7 months or more. Under such conditions the sluice would be closed for the most of the hydro-year.

[D] Lake level highstands, when water levels are above the 850 m stage-height for the entire hydro-year. Under such conditions the sluice would not be closed; consequently there is continuous outflow from Lesser Prespa Lake through the Koula channel to Greater Prespa Lake. Hydro-annual lake level is approximately “stable” under these conditions.

3.2 Precipitation-based thresholds

Precipitation data from the Prespa catchment best explain lake level variability (van der Schriek and Giannakopoulos 2017) as local climates are different in adjacent basins (e.g. Ohrid; Popovska and Bonacci 2007). Comparison of lake level data with the wet season precipitation yields particularly good results. The relation of lake level with parameters on shorter timescales is poor, as is common in geologically complex Mediterranean lakes that experience significant summer evaporation and snow-melt input (e.g. Elias and Ierotheos 2006).

Detailed water level and precipitation data are available for Greater Prespa Lake (see section 2). When wet season precipitation is <500 mm, there is a fall in lake level from October $_{\text{year1}}$ to October $_{\text{year2}}$. If the wet season precipitation <405 mm ***and*** annual precipitation <680mm, there is a significant annual fall in lake level (of more than -0.65 m) and there is no wet season lake level peak at all (severe drought; continuous falling water level throughout the year).

Although no reliable water level record for Lesser Prespa Lake exists before 1969, water level movements can be inferred from the Greater Prespa Lake level record that starts in 1951. The lakes were fully communicating up to 1976, and their monthly average water levels were within 0.2 m of each other. Water level fluctuations of the combined lakes prior to 1976 are driven by the cumulative 6-month (Oct-Mar) wet season precipitation as stated by van der Schriek and Giannakopoulos (2017).

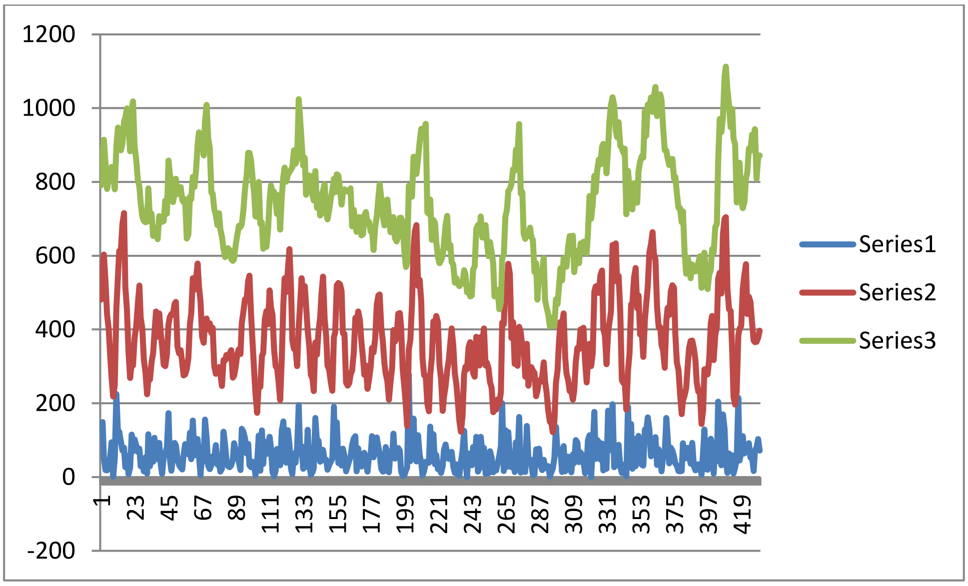


Figure 3.1 Precipitation (1951-2004) in the Prespa Basin: monthly (series 1), running 6-month (series 2) and running 12-month (series 3) averages

The Lesser Prespa Lake level record is compared to the local monthly precipitation record of the Prespa catchment (section 2.2) that spans the years 1951-2004. Figure 3.1 shows the monthly, running 6-month and running 12-month precipitation over the observation period. For the part of the Lesser Prespa Lake record spanning 2004-2016 there are no reliable local precipitation records available; the E-OBS gridded European dataset (see section 2.2) is not highly correlated to the local catchment precipitation and is therefore not used for the definition of threshold-precipitation values. Furthermore, since 2005 the sluice has been regulating outflow. As there was free outflow above the spillway at 849.60 m before 2005, the water level record prior and post sluice-installation cannot be directly compared. Given the aforementioned reasons, this analysis has therefore focused on the water level record of Lesser Prespa Lake spanning 1969-2004.

The cumulative 6-month wet season precipitation in March was chosen to define wet season rainfall thresholds associated with specific water level analogues and lake stage-heights. Wet season precipitation was selected due to its proven high correlation with water level prior to 1976. The following precipitation thresholds have been established:

[A] Significant lake level lowstands are defined as water levels that are <850 m for the 12 months of the hydrological year (October $_{\text{year1}}$ to September $_{\text{year2}}$) ***and*** below 896,6 m for 5 months and more. These lowstands occur when the 6-month cumulative wet season (Oct-Mar) precipitation is **below 370 mm** (20th percentile; Table 3.1). This wet season rainfall affects water levels up to 12 months ahead as next seasonal lake lowstand will be below 850 m for 5-7 months. Extreme lake level lowstands **[B]**, when water level is at or below 849 m, occur when **two subsequent wet seasons receive less than 370 mm** of precipitation each. Two such wet seasons in a row affect water levels up to 12 months ahead as the lake will remain below 849.60 m for this entire period.

Water levels that are below 850 m for 7 months or more **[C]** occur when the 6-month cumulative wet season (Oct-Mar) precipitation is **below 415 mm** (40th percentile; Table 3.1). Wet season precipitation values that fall within this category are observed frequently, as indicated by the percentiles.

Water levels that are above 850 m for the entire hydro-year **[D]** are taking place very infrequently, when the 6-month cumulative wet season (Oct-Mar) precipitation is **above 560 mm** (90th percentile; Table 3.1). For all other years, characterized by wet season precipitation between 415-600 mm, lake level falls below the 850 m mark for one to six months.

	P (mm)
average	455,79
5th	284,40
10th	310,80
15th	355,10
20th	377,60
25th	390,70
75th	518,00
80th	529,60
85th	544,60
90th	566,80
95th	635,90

Table 3.1 Wet season precipitation (Oct-Mar) statistics: averages and percentiles

3.3 Precipitation thresholds and drought indices

Drought is a natural hazard that results from lower levels of precipitation than what is considered normal at a given location. When this phenomenon extends over a season, precipitation is insufficient to meet the demands of human activities and the environment. Drought must be considered a relative, rather than absolute, condition both in space and time.

There are many different methodologies for monitoring drought. The Standardized Precipitation Index (SPI) devised by McKee et al. (1993, 1995) for the definition of drought is a powerful, flexible index that is simple to calculate with precipitation being the only required input parameter. In addition, it is just as effective in analysing wet periods/cycles as it is in analysing dry periods/cycles. The SPI can be computed for different time scales, provide early warning of drought and help assess drought severity. The World Meteorological Organization (WMO) selected the SPI as a key indicator to be produced operationally by National Meteorological and Hydrological Services around the world to characterize drought (WMO, 2012).

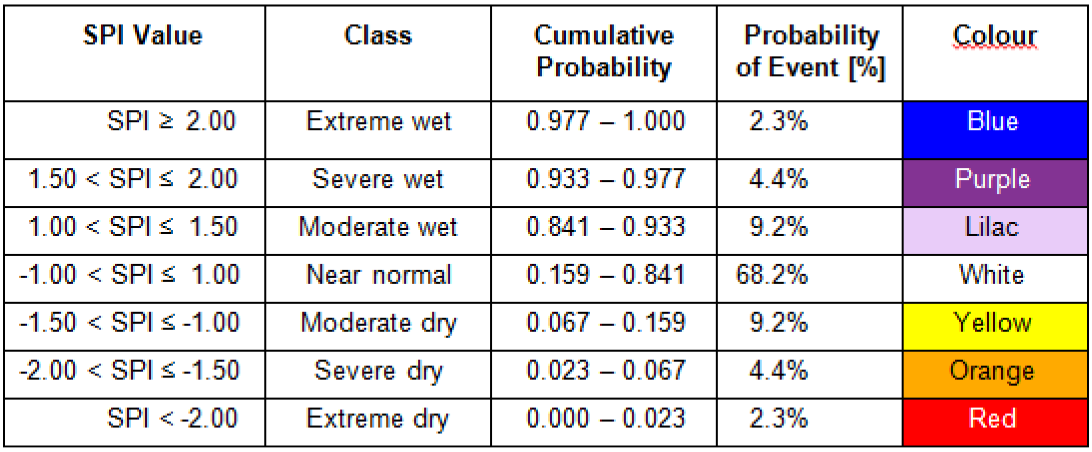
This study has selected the SPI for the analysis of wet- and dry periods in the Prespa catchment as it is a powerful, flexible index that is simple to calculate with only monthly precipitation records.

3.3.1 SPI: description

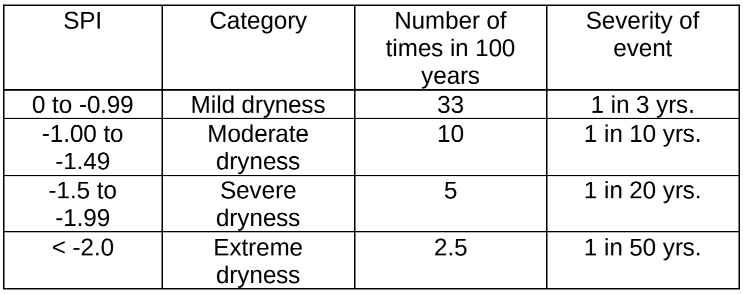
The Standardized Precipitation Index (SPI-*n*) is a statistical indicator comparing the total precipitation received at a particular location during a period of *n* months with the long-term rainfall distribution at that location. SPI is calculated on a monthly basis for a moving window of *n* months, where *n* indicates the rainfall accumulation period, which is typically 1, 3, 6, 9, 12, 24 or 48 months. The corresponding SPIs are denoted as SPI-1, SPI-3, SPI-6, etc. In order to allow for the statistical comparison of wetter and drier climates, SPI is based on a transformation of the accumulated precipitation into a standard normal variable with zero mean and variance equal to one. A full description of the SPI computational procedure can be found in McKee et al. (1993, 1995). SPI results are given in units of standard deviation from the long-term mean of the standardized distribution (Guttman 1999).

A reduction in precipitation with respect to the normal precipitation amount is the primary driver of drought, resulting in a successive shortage of water for different natural and human needs. Since SPI values are given in units of standard deviation from the standardised mean, negative values correspond to drier periods than normal and positive values correspond to wetter periods than normal. The magnitude of the departure from the mean is a probabilistic measure of the severity of a wet or dry event. The SPI can be presented in the form a time series graphs for a single location. SPI values as a measure of the severity of a wet or dry event, as well as recurrence periods, are summarized in Table 3.2.

The WMO recommends that precipitation totals for at least 30 years are used as reference time-line for calculating rainfall statistics. Recent periods (e.g. 1971-2000) are used in order to accommodate changes in the precipitation regime due to climate change and to compare actual rainfall figures to a recent situation. For an accurate representation of extreme events, however, it is recommend calculating the statistics for the SPI from even longer time periods (e.g. 50 or more years). Statistically, 1–24 months is the best practical range of application (Guttman, 1999) when around 50–60 years of data are available. Unless one has 80–100 years of data, the sample size is too small and the statistical confidence of the probability estimates on the tails (both wet and dry extremes) becomes weak beyond 24 months.



SPI Value	Class	Cumulative Probability	Probability of Event [%]	Colour
SPI ≥ 2.00	Extreme wet	0.977 – 1.000	2.3%	Blue
1.50 < SPI ≤ 2.00	Severe wet	0.933 – 0.977	4.4%	Purple
1.00 < SPI ≤ 1.50	Moderate wet	0.841 – 0.933	9.2%	Lilac
-1.00 < SPI ≤ 1.00	Near normal	0.159 – 0.841	68.2%	White
-1.50 < SPI ≤ -1.00	Moderate dry	0.067 – 0.159	9.2%	Yellow
-2.00 < SPI ≤ -1.50	Severe dry	0.023 – 0.067	4.4%	Orange
SPI < -2.00	Extreme dry	0.000 – 0.023	2.3%	Red



SPI	Category	Number of times in 100 years	Severity of event
0 to -0.99	Mild dryness	33	1 in 3 yrs.
-1.00 to -1.49	Moderate dryness	10	1 in 10 yrs.
-1.5 to -1.99	Severe dryness	5	1 in 20 yrs.
< -2.0	Extreme dryness	2.5	1 in 50 yrs.

Table 3.2 The value of the SPI gives a measure of the severity of a wet or dry event, and the probability of recurrence, as summarised. SPI Classification following McKee et al. (1993)

Since the SPI can be calculated over different rainfall accumulation periods, SPIs allow for estimating different potential impacts of drought:

- SPIs for short accumulation periods (e.g., SPI-1 to SPI-3) are indicators for immediate impacts such as reduced soil moisture, snowpack, and flow in smaller creeks;

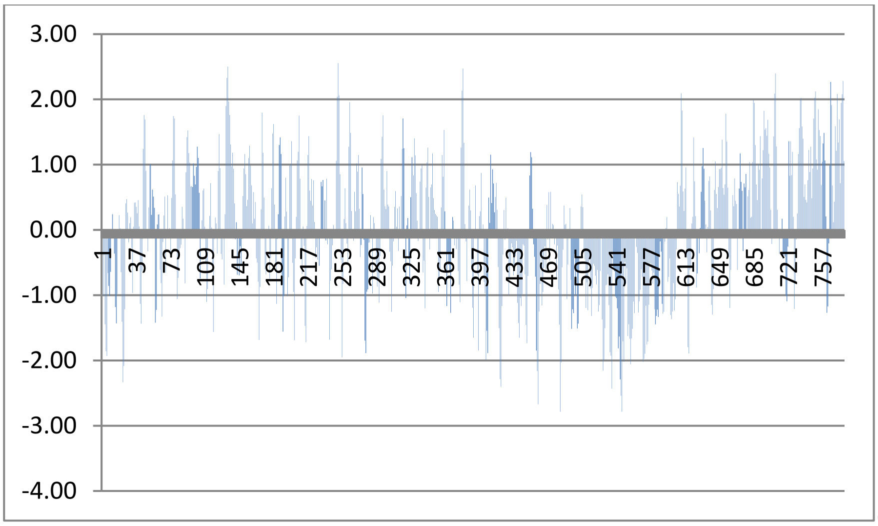
- SPIs for medium accumulation periods (e.g., SPI-3 to SPI-12) are indicators for reduced stream flow and reservoir storage; and

- SPIs for long accumulation periods (SPI-12 to SPI-48) are indicators for reduced reservoir and groundwater recharge, for example.

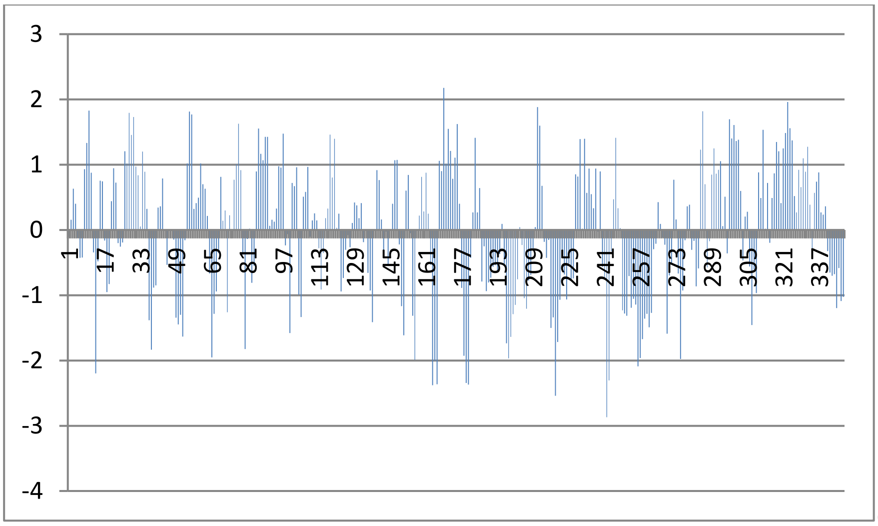
The exact relationship between accumulation period and impact depends on the natural environment (e.g., geology, soils) and the human interference (e.g., existence of irrigation schemes). In order to get a full picture of the potential impacts of a drought, SPIs of different accumulation periods should be calculated and compared.

3.3.2 SPI values for the Prespa catchment: time-series 1953-2004 and 1971-2000

This report calculates SPI-values for the Prespa catchment, based on two time-series. Precipitation totals for the 30-year period from 1971-2000 are used, in line with WMO recommendations, in order to accommodate minor observed changes in the precipitation regime due to climate change (van der Schriek and Giannakopoulos 2017) and to compare actual rainfall figures to a more recent situation. Future SPI-values, based on model projections, are also calculated over a 30-year period (section 5) thus making comparison possible. Secondly, SPI-values are calculated based on the full available precipitation series from 1951-2004. Such long time-period allows for an accurate representation of extreme events (McKee et al. 1993, 1995). SPI values are calculated for 3, 6, 9, 12 and 24 months, as this is the best practical range of application (Guttman, 1999). The SPI-1 is not chosen as its interpretation may be misleading: in Mediterranean regions where rainfall is normally low during certain months, large negative or positive SPIs may result - even though the departure from the monthly mean is relatively small.



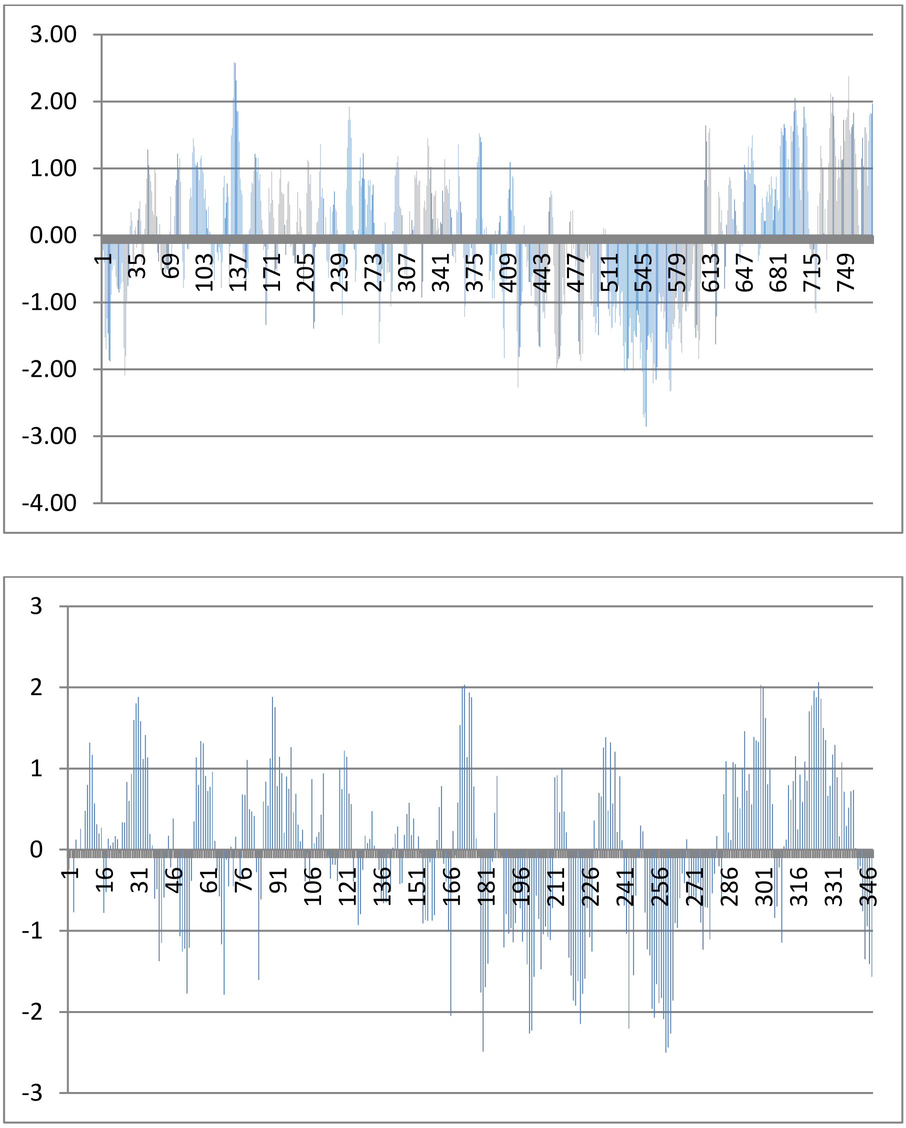
(a)



(b)

Figure 3.2 (a) SPI-3, 53 year time-series (1951-2004), (b) SPI-3, 30-year time-series (1971-2000)

Figure 3.2: The 3-month SPI reflects short- and medium-term moisture conditions and provides a seasonal estimation of precipitation. It is important to compare the 3-month SPI with longer timescales. Looking at longer timescales can prevent misinterpretation believing that a drought might be over when in fact it is just a temporary wet period. The 3-month SPI may be misleading in regions where it is normally dry during any given 3-month period. Large negative or positive SPIs may be associated with precipitation totals not very different from the mean.



(a)

(b)

Figure 3.3 (a) SPI-6, 53 year time-series (1951-2004), (b) SPI-6, 30-year time-series (1971-2000)

Figure 3.3: The 6-month SPI indicates seasonal trends in precipitation and is considered to be very sensitive to conditions at this scale. The SPI-6 is very effective in showing precipitation over distinct seasons. Specifically, the SPI-6 at the end of March gives a very good indication of the amount of precipitation that has fallen during the important wet season period from October through March for Mediterranean sites. SPI-6 values may be associated with anomalous streamflows and reservoir levels.

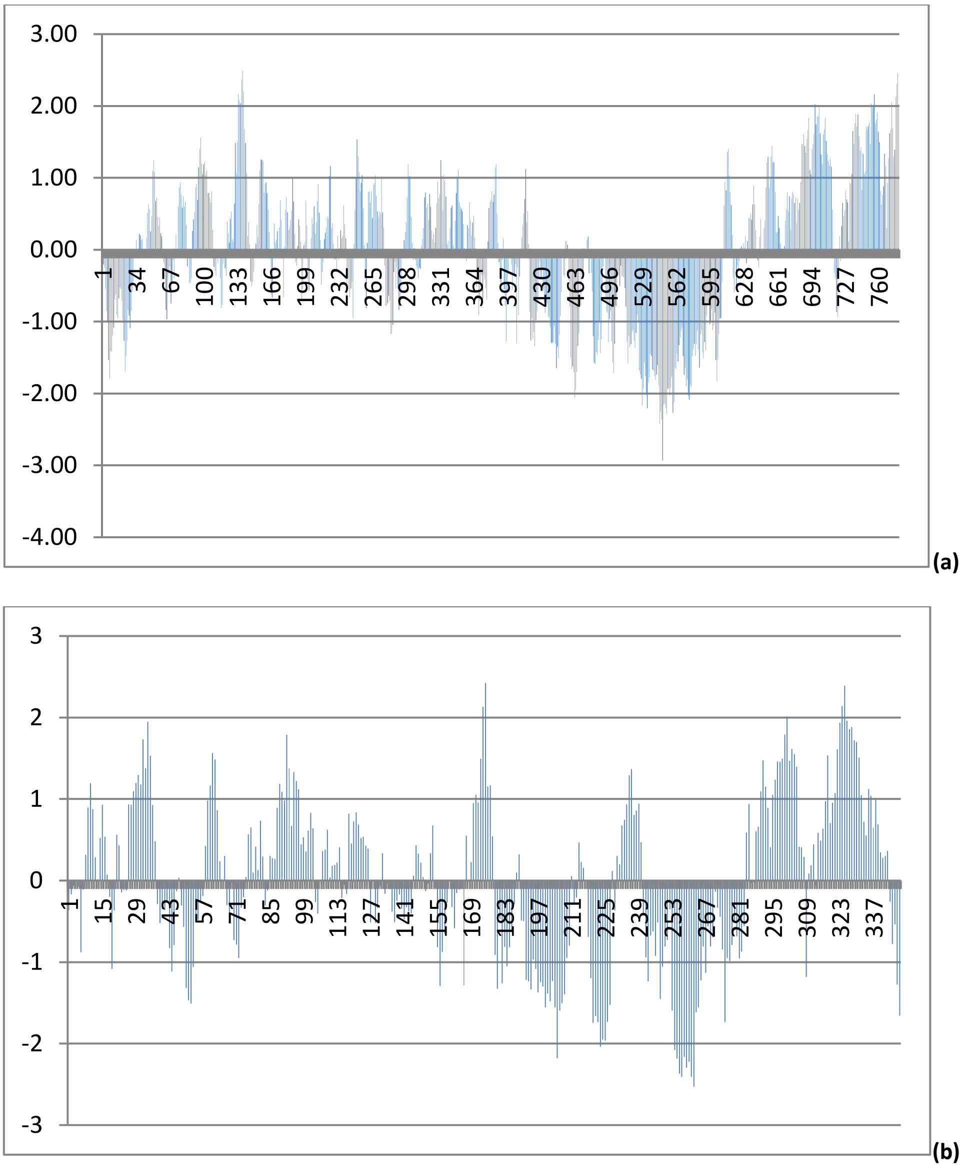


Figure 3.4 (a) SPI-9, 53 year time-series (1951-2004), (b) SPI-9, 30-year time-series (1971-2000)

Figure 3.4: The 9-month SPI provides an indication of inter-seasonal precipitation patterns. Droughts usually take a season or more to develop. SPI values below -1.5 for these timescales are usually a good indication that dryness is having a significant impact on agriculture. This time period begins to bridge shorter-term seasonal drought to longer-term droughts that may become hydrological, or multi-year, in nature.

Figure 3.5: The 12-month and 24-month SPI reflects long-term precipitation patterns. Because these timescales are the cumulative result of shorter periods that may be above or below normal, the longer SPIs tend to gravitate toward zero unless a distinctive wet or dry trend is taking place. SPIs on these timescales are usually tied to streamflows, reservoir levels, and even groundwater levels.

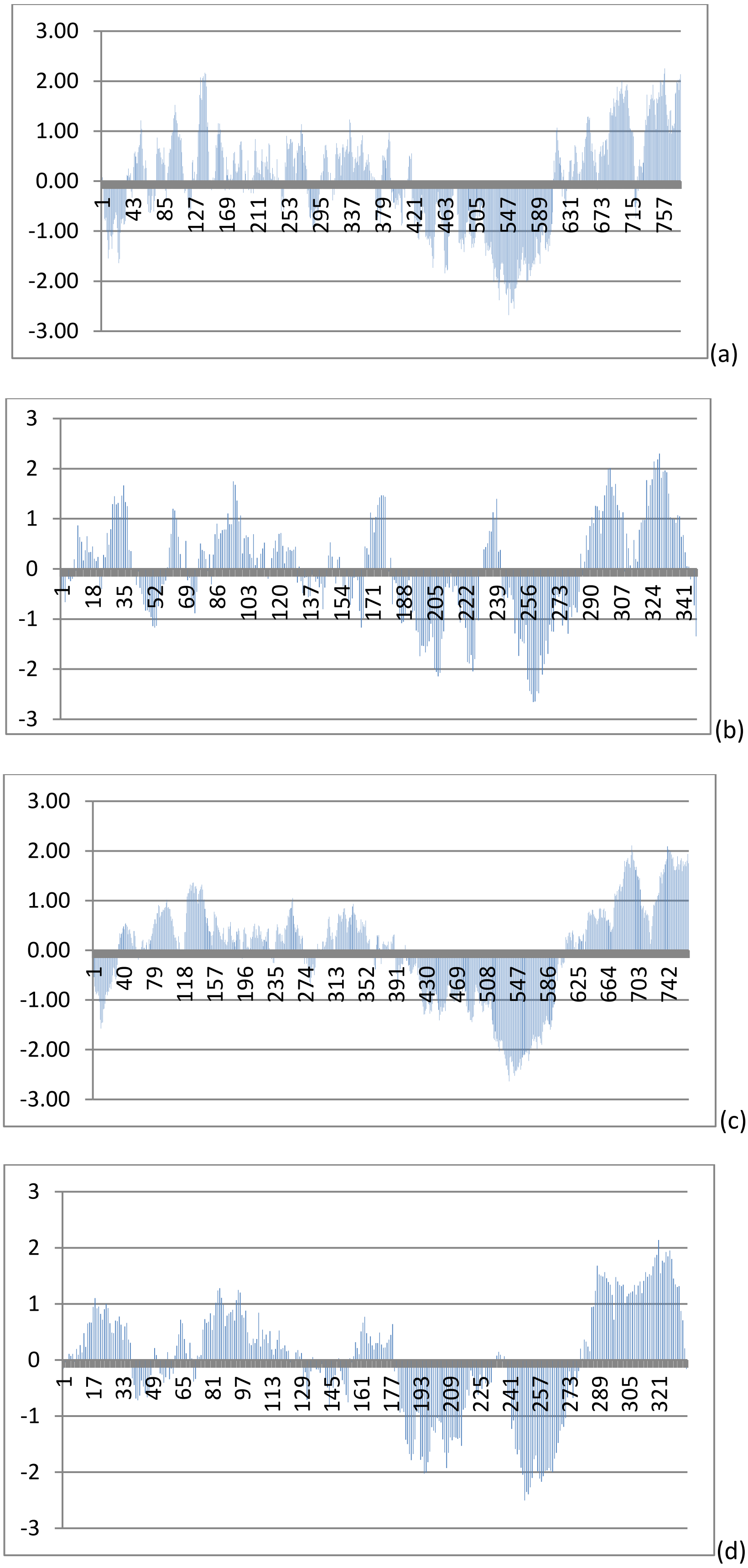


Figure 3.5 (a) SPI-12, 53 year time-series (1951-2004), (b) SPI-12, 30-year time-series (1971-2000), (c) SPI-24, 53 year time-series (1951-2004), (d) SPI-24, 30-year time-series (1971-2000)

3.3.3 Dry- and wet periods: influence on water level of Lesser Prespa Lake

Different monthly SPI values for the period covering 1969-2004 (1971-2000) show broadly the same pattern. There is a declining trend line up to 1993, followed by a rising trend line. As expected, the short term variability declines with increasing the amount of months used for calculating the SPI. A similar pattern of dry-wet periods is particularly displayed by the 6-, 9-, 12, and 24-month SPIs (Figs. 3.2-3.5). There is limited difference between SPI values based upon the long (53-year) and short (30-year) time-series. Dry events on the long time-series are slightly more negative (max. by 0.1 for the same month/year), because the years "missing" in the shorter time-series were on average wet. This difference can be neglected.

Dry events of < -1 (moderate dryness; Table 3.2) are concentrated around 1976-1977 and 1983-1986, while dry events reaching -2 (severe to extreme dryness; Table 3.2) are concentrated around 1988-1991, 1993-1995 and 2000-2002. These periods correspond to multi-annual regional and Mediterranean-wide drought events that are well-documented in the literature (e.g. Livada and Assimakopoulos 2007, Mavromatis 2011). These dry periods correlate to periods with low water level.

As stated in section 3.2, lake level behavior is best explained by looking at the cumulative wet season precipitation by the end of March. To connect precipitation-thresholds to drought conditions, it is best to use the SPI-6 at the end of March. This value is known to give a very good indication of the amount of precipitation that has fallen during the important wet season period (October to March) for Mediterranean sites. Only for extreme lake level lowstands, when wet season precipitation is below 370 mm for 2 or more consecutive years (section 3.2), the SPI-24 by the end of march is a useful indicator.

The following SPI values in March can be linked to specific lake level analogues and wet season precipitation thresholds:

[A] Significant lake level lowstands (water levels <850 m for 12 months of the hydrological year ***and*** below 896,6 m for 5 months and more) occur when the 6-month wet season precipitation is **below 370 mm** (20th percentile; Table 3.1). The associated SPI-6 (for March) ranges between -1.1 to -1.7. The related conditions are described as "moderate dryness" (> -1.5) to "severe dryness" (<-1.5); such events occur once every 10 to 20 years (Table 3.2).

[B] Extreme lake level lowstands (water level at or below 849 m for several months and below 849.6 m for at least one hydro-years) occur when **two subsequent wet seasons receive less than 370 mm** of precipitation each. The associated SPI-6 (for March) is <-1.5, indicative of "severe dryness" and occurring once every 20 years (Table 3.2). However, a better indicator is the associated SPI-24 (for March after the 1st year receiving <370 mm wet season precipitation), which is at -2.1 and indicates "extreme dryness" occurring once in 50 years.

[C] Water levels below 850 m for 7 months or more occur when the wet season precipitation is **below 415 mm** (40th percentile; Table 3.1). Wet season precipitation values that fall within this category are observed frequently, as indicated by the percentiles. The associated SPI-6 (for March) ranges between -0.6 and -1.0, and related conditions are described as “mild dryness” that take place once in 3 years (Table 3.2).

[D] Lake highstands (water levels above 850 m for the entire hydro-year) occur when the wet season precipitation is **above 560 mm** (90th percentile; Table 3.1). The associated SPI-6 (for March) ranges between 1.0 and 1.4, and related conditions are described as “moderate wet” that take place once in 10 years (Table 3.2).

3.4 Air- to Lake Surface temperature correlations

Lake temperature influences biological (e.g. fish spawning) and bio-chemical processes, impacting thus upon, for example, eutrophication. It is therefore an important variable that is strongly affected by projected future climate change. There is an established relation between lake surface temperature and air temperature; observational records of both variables show a high degree of correlation. A linear regression of recorded lake surface temperature and air temperature will yield a function that may be used to predict one variable based on the other. This method is robust, although not sensitive, and it produces reasonable estimates when using average monthly values (Sharma *et al*. 2008).

This paragraph aims to establish the relationship between observed monthly maximum air temperature and lake surface temperature of Lesser Prespa Lake, using linear regression. This relationship makes it possible to provide reliable estimates of future lake surface temperature based on the modelled future monthly maximum air temperature projections (section 6), which are considered highly reliable.

3.4.1 Approach

Monthly maximum air temperatures for the Prespa catchment were obtained from the E-OBS gridded European data-series (Haylock et al. 2008). The E-OBS temperature data were selected because of their continuous nature over the time-period of interest and their high correlation to local (discontinuous) temperature series (van der Schriek and Giannakopoulos 2017). Monthly lake surface temperatures are available for most months from 1995 to 2016 from the local Koula station (Table 3.3); these data were not subjected to any quality control. The data are suitable for the robust method of linear regression between monthly air and surface temperatures (Sharma *et al*. 2008). Non-parametric bootstrap confidence intervals (95th percentile) were employed to detect if the regression is statistically significant (Diciccio 1996, Varotsos *et al*. 2013).

	jan	feb	mar	apr	may	june	jul	aug	sep	oct	nov	dec
1995	x	x	x	13,1	16,0	21,4	22,2	21,5	x	x	x	x
1996	x	x	x	x	x	x	x	x	x	x	x	x
1997	4,9	5,4	8,4	9,2	18,4	23,9	23,6	23,4	20,1	14,4	7,7	4,6
1998	4,4	4,8	6,5	12,5	16,4	21,6	26,0	23,0	17,6	16,3	9,4	3,4
1999	3,2	2,8	7,4	12,4	18,8	23,3	25,2	25,5	21,2	17,2	9,3	5,8
2000	1,9	2,9	7,0	13,3	19,7	22,8	23,6	24,6	21,3	17,4	11,8	7,3
2001	3,6	4,9	9,6	12,6	14,8	19,5	22,9	23,6	20,1	17,9	9,8	1,1
2002	x	4,7	9,4	15,5	19,4	22,6	24,1	23,4	20,6	14,2	11,8	4,8
2003	3,7	2,7	4,8	11,6	22,9	25,7	25,4	25,4	20,2	13,8	9,4	5,2
2004	1,2	3,0	5,3	10,5	17,5	22,4	25,4	23,3	19,9	16,5	11,2	6,5
2005	1,5	1,0	7,6	13,4	19,1	22,1	23,9	22,9	19,8	16,0	10,3	5,0
2006	1,7	2,1	6,5	12,8	17,5	21,0	22,2	22,8	18,6	16,7	12,5	10,2
2007	5,5	6,1	9,0	14,4	20,0	23,1	25,2	24,6	19,7	14,8	8,1	3,3
2008	1,4	3,2	9,1	12,3	18,1	24,5	25,4	25,0	17,7	15,0	11,8	6,4
2009	4,1	4,6	6,9	12,6	19,8	22,5	24,8	23,3	20,3	14,8	9,6	7,0
2010	4,1	5,0	7,6	14,1	19,1	22,3	25,2	24,5	19,7	15,3	12,0	7,6
2011	3,7	5,1	6,9	11,3	16,3	22,5	24,6	24,3	22,4	12,0	8,0	5,0
2012	0,2	0,0	8,3	12,4	18,3	25,0	27,3	25,2	21,6	18,6	10,5	4,3
2013	4,0	5,3	7,8	12,6	20,0	20,9	22,7	23,3	19,7	16,2	11,9	3,9
2014	5,2	7,0	9,4	13,8	18,4	21,7	23,8	23,4	21,4	14,4	10,3	6,2
2015	2,5	3,9	7,8	11,5	19,2	22,5	24,2	24,8	21,5	15,9	10,1	6,0
2016	4,6	7,5	9,5	16,9	18,8	23,7	25,6	24,8	21,3	15,3	8,9	5,3

Table 3.3 Lesser Prespa Lake: monthly lake surface temperatures

3.4.2 Results

E-OBS maximum monthly air temperature and local monthly lake surface temperature were found to be highly correlated (r=0.978), and statistically significant (95th percentile bootstrap confidence intervals: 0.973 – 0.982). The relationship can be described by the following formula, where (y) is monthly lake surface temperature and (x) is monthly maximum air temperature: $y = 0.9924x + 0.8762$. Figure 3.6 shows the linear correlation. This correlation can be used for future estimates of lake temperature based on model projections of air temperature, given the very strong correlation between variables. Such impact projections are presented in section 6.

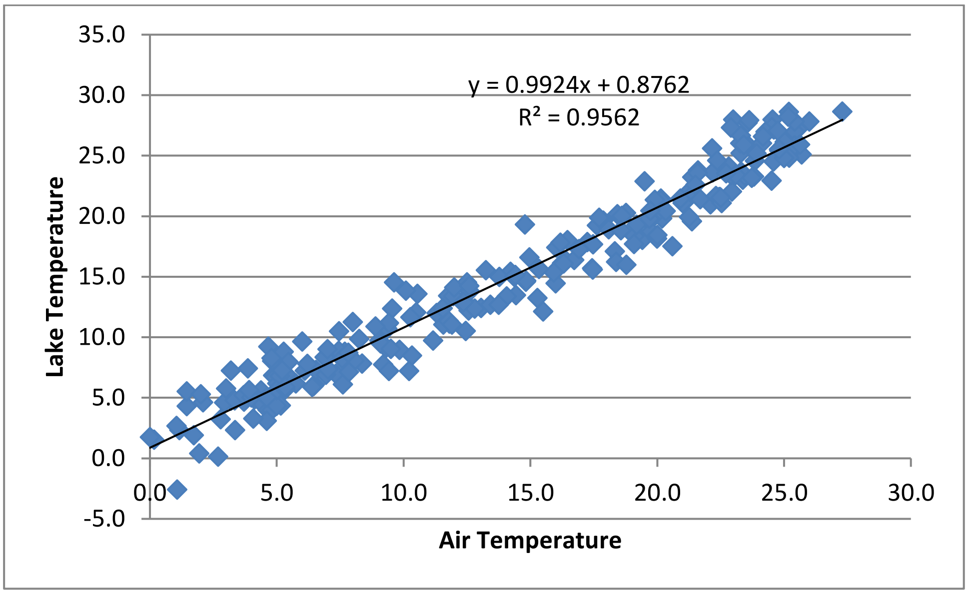


Figure 3.6 Linear correlation of monthly maximum temperature (in °C) and monthly lake surface temperature (in °C) for Lesser Prespa Lake

4. Lesser Prespa Lake: water level variability and changes in reedbed / wet meadow extent

This section evaluates how observed water level variability affected shoreline position and reedbeds / wet meadows that fringe the alluvial lake margins. Specifically, shoreline positions associated with low- and highstand lake analogues (section 3) will be assessed as these inform future impact analyses (section 6) and creation/management of wet meadows (section 8). Fire-access to reedbeds is also discussed, drawing upon observational data.

4.1 Context

Reedbeds are currently rooted around the alluvial lake margins in the height-range from approximately 848 m to 851 m, which roughly corresponds to the maximum and minimum water levels observed since 1969 in Lesser Prespa Lake (section 2.5; Fig. 2.2). Their upper height limit is mainly determined by agriculture: groundwater levels permit intensive cultivation above 851 m. The lower limit is a function of water depth.

At present, wet meadows are only maintained in a few selected places by management activities such as mowing and cattle grazing at the landward edge of the reedbelt. Active wet meadows occupy the height-range around 850 m; sluice management aims to have these meadows flooded in April (Parisopoulos *et al*. 2007). Wet meadows are thus located within the zone that can be occupied by reedbeds. Without management activities they become overgrown by reeds.

Lake level lowstands (analogues A, B and C; section 3) are associated with (i) a decrease in seasonal water level variability, and (ii) retreating lake shorelines, to within the reedbelt. This causes the existing wet meadows to be flooded only partially or not at all. If wet meadows are to be expanded around the lake, it is essential that part of them is flooded even under lowstand lake level conditions. Finally, fire-access to reedbeds is facilitated by lake level lowstands as vegetation on higher grounds around the lake dries out and provides access routes to deep within the reedbelt.

4.2 Water level fluctuations and lake-shore changes

To assess the impact of water level variability on shoreline position and the reed / wet meadow zone around the margin of Lesser Prespa Lake several data were analysed, including: aerial photographs (1945, 1970, 1979, 1982, 1992, 1995 and 2008), high-resolution satellite images (accessed through GoogeEarth_Pro), digital elevation models of the shoreline, geological and topographical maps. Specifically, the reedbed / wet meadow zone along the margins of Lesser Prespa Lake at 12/07/2017 has been plotted using high-resolution satellite images (Fig. 4.1). This situation has been compared to high-resolution satellite images dating from 12-1984, and to the available aerial photographs.

Figure 4.1 shorelines and reed-belt around Lesser Prespa Lake

4.2.1 Shoreline movements

The shoreline associated with seasonal high lake levels (spring-summer) is located at the landward edge of the continuous reedbeds during near normal to wet years (SPI-6 in March >0; section 3.3.3). However, during years characterised as moderate to severe dry (SPI-6 in March < -1.1), the shoreline over the same time-period is located within the reedbelt.

During the seasonal low lake level period (autumn-winter), the shoreline fluctuates within the reedbed zone. The shoreline is near or at the outer edge of the continuous reedbeds during seasonal lowstands of years that are characterised as moderate to severe dry (SPI-6 in March < -1.1; section 3.3.3). The shoreline remains at the outer edge of the reedbelt during multi-seasonal extreme lowstands that are characterised by extreme dryness (SPI-24 in March < -2).

Reedbeds occupy formerly cultivated (ploughed) areas around the lake margin (Fig. 4.2). Such areas are found at elevations from 851 m down to at least 849 m (at present usually below lake level). These formerly cultivated areas show linear features perpendicular to the lake, a ridge-and swale topography of up to 50 cm height-difference that facilitated drainage, and are having a higher elevation than the immediately surrounding zones. Here reedbeds dry out most during autumn-winter, especially during dry years, as indicated by their change to a yellow-brown colour up to the water edge.

Figure 4.2 Formerly cultivated (ploughed) areas around the margin of Lesser Prespa Lake

4.2.2 Reedbelt changes

The width of the reedbeds fringing Lesser Prespa Lake has been remarkably stable over the period covered by the water level record (1969-2016). The notable exception is the SW extremity of the lake (located in Albania), where the lake has been filled-in through sediment discharged by the Devolli-diversion (section 2.4; GFA Consulting 2005). Along the other alluvial parts of the shoreline there have been only very minor, local, adjustments.

Figure 4.3 Shorelines and reed-belt around Lesser Prespa Lake: SW extremity

The lake has been rapidly infilling from the Wolf Pass, at the SW extremity of the Lake located in Albania. Here, large amounts of sediments were deposited during the operation of the Devolli River Diversion (1976-2000). As a consequence, reedbeds have expanded significantly in this area due to the shallowing of the lake bottom (Fig. 4.3).

Figure 4.4 Shorelines and reed-belt around Lesser Prespa Lake: NW lake margin

Along the NW alluvial lake margin near Pyli, the inner margin of the reedbeds has moved lakewards, due to expansion of cultivated fields (Fig. 4.4). However, this change is very minor. Aerial photos show that the inner margins of reedbeds around the alluvial shores of the lake are cleared during consecutive dry years (solely parts which have been cultivated in the past). Most of these clearances are abandoned once lake level rises again.

The N alluvial shores of Lesser Prespa Lake experienced some limited changes over the past decades. Near the causeway to Aghios Achilleos Island, the area with thick reedbeds has expanded (Fig. 4.5). Perhaps this was caused by less mooring/fishing and grazing pressure. Around the island itself the reedbeld has slightly decreased in thickness. This might be linked to a strong reduction in sediment supply, as the ploughed fields adjacent to the lake all disappeared after the 1970s.

The Koula channel through the isthmus has narrowed and filled with reed since the 1970s (Fig. 4.6). This is likely linked to the installation of the sluice and the end of water flow in the channel, leading to its infill. There are some other minor adjustments in the reedbelt position near the entrance of this channel at Lesser Prespa Lake , that are likely also associated with the cessation of significant water flow in the channel. The open-water bodies in the Koula isthmus appear to contain fewer reeds and have a slightly larger surface area in 2017 compared to 1970. It has been documented that the open water bodies at this location changed after the extreme lowstand of the lake around 1987-1995 (Catsadorakis and Malakou 1997). Oxidation of organic material during lake lowstands may have led to expansion of the local troughs occupied by water bodies.

Figure 4.5 Shorelines and reed-belt around Lesser Prespa Lake: Aghios Achilleos Island

Figure 4.6 Shorelines and reed-belt around Lesser Prespa Lake: the isthmus (N)

Along the E-side of the lake, from the isthmus south to Mikrolimeno, there are three local sites where reedbeds have expanded (Fig. 4.7). All of these sites are located at (former) river mouths; reeds have expanded on their shallow fan-delta complexes. The fact that all river mouths are now overgrown, indicates: 1] a low(er) sediment supply due to land-use changes (abandonment of upland cultivation; esp. visible at Mikrolimeno), and 2] a low(er) water discharge, without large peak events. In case 1 and 2 were high, reedbeds could not establish or would be periodically removed.

Figure 4.7 Shorelines and reed-belt around Lesser Prespa Lake: NE and NW shores

4.3 Long-term water level variability and land-use changes: impacts on lake-shore habitats

The longer water level record of Greater Prespa Lake, which is indicative for Lesser Prespa Lake prior to 1976 (section 2.5.1), shows that water level amplitudes over multiple decades (from 847.50 m to 852 m) were much larger. Reed must have expanded into the lake during prolonged lowstands, while organic material above the groundwater table experienced oxidation (i.e. removal). The installation of a weir and, especially, the sluice system greatly reduced long- and short-term natural lake level variability. Vegetation belts became fixed in a narrow altitudinal zone. Furthermore, the reduction in water and sediment discharge from the surrounding streams (a combination of water abstraction, abandonment of upland cultivation and less overland-runoff and canalisation) led to the clogging-up of stream mouths and former deltas by reeds.

Recent wet meadows were only maintained through agricultural management practices, such as mowing/burning and cattle holding in the zones around the lake. However, with the abandonment of traditional agricultural toward the end of the 1960s, reedbeds expanded to occupy these formerly open, periodically flooded, areas. It is estimated that reedbeds increased by 25% from 1945 to the 1980s, to the detriment of wet meadows around the lake (Catsadorakis and Malakou 1997).

Prior to weir/sluice installation, significant changes in water level occurred that were followed by significant changes in the location/width of the reed-belt and wet meadows. Falling levels led to the expansion of cultivation and the lakeward-shift of wet meadows; consequently the expansion of reeds within the lake was balanced by a removal of older reedbeds at the landward margin. Large lake level rises led to abandonment and drowning of cultivated fields near the shore, occupation by young reeds and drowning of the deepest reedbeds; thus again a renewal of the reedbeds took place.

Traditional land-use in relation to longer-term lake level change therefore led to the removal of nutrients (oxidation, ploughing, cattle-feed, reed-burning) and renewal of reed, while limiting the width of the reedbelt. This likely led to less dense, younger and more species-diverse reedbeds compared to the present situation. Secondly, there is no longer a significant flow between the lakes (thus less fluxing out of pollutants/nutrients). Both factors increase the pollutant/nutrient concentration thus amplifying eutrophication and affecting (likely) reedbed density / species composition.

4.4 Reedbed fires: observations

There is a systematic record of reedbed fires around the Greek shoreline of Lesser Prespa Lake spanning the years 2007-2016, based on data collected by the SPP from: SPP photo archive, SPP drone photo archive, Prespa Park Wetland Management Committee reports, and Prespa Park Management Body reports. Fires are on record for six years (2007, 2008, 2012, 2014, 2015 and 2016) and their location / extent is given in figure 4.8. Most fires take place in February and March, during the wet season and under rising seasonal lake level. The timing is related to fires started by farmers to clean fields and drainage ditches; occasionally these spread into the reedbeds.

The record contains too few data for statistical analyses of drought conditions and reed-fires. However, none of these fires started during a period that can be characterized as “dry” based on E-OBS derived SPI-3 and SPI-6 values; fires during the years 2014 to 2016 even started under moderate wet conditions. A link between reedbed fires and drought does therefore not seem plausible.

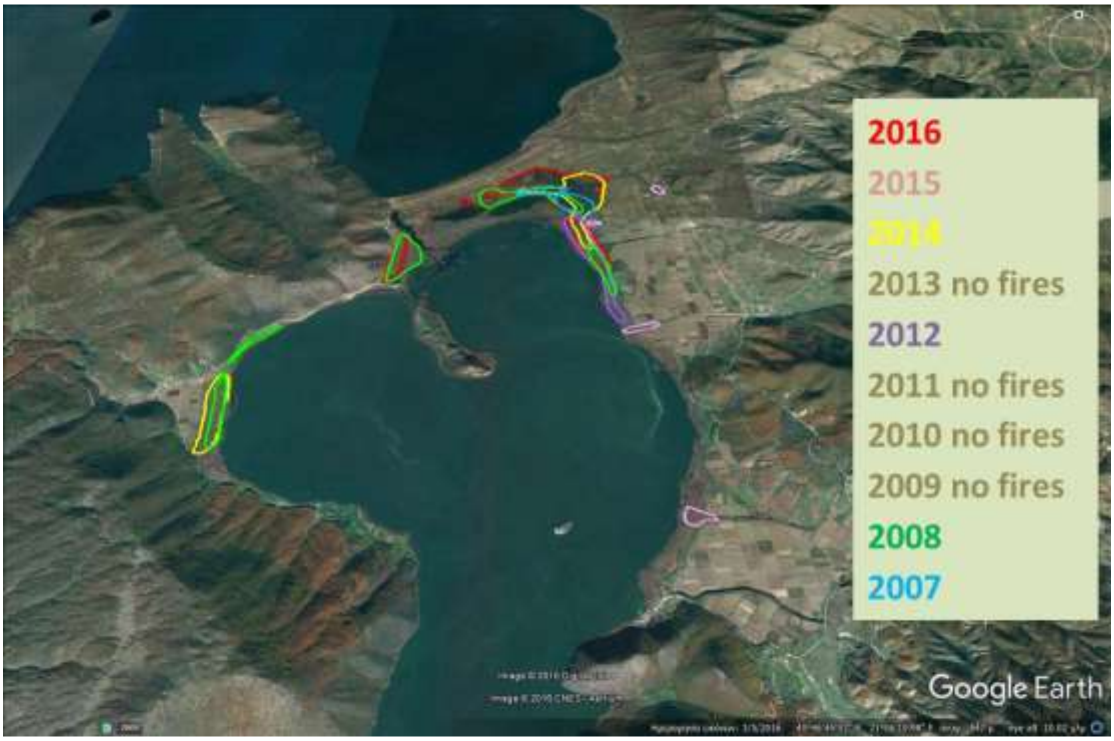


Figure 4.8 Reedbed fires (2007-2016). Based upon data collected by the SPP (SPP photo archive, SPP drone photo archive, Prespa Park Wetland Management Committee reports, Prespa Park Management Body reports)

Lake levels were near 850 m, except for 2008, when they were 30 cm lower. Fires in 2008 were most widespread. It seems likely that low lake levels facilitated the spread of fire into reebeds. Fires started in fields adjacent to reedbeds, or in vegetation clogging drainage ditches that directly connected to reedbeds. Reedbeds located on higher grounds (+850 m) were particularly susceptible to fire. Fires around the isthmus were hampered in their spread by the presence of water bodies and channels. The observed invasion of reeds into channels and channel mouths (section 4.2) is therefore facilitating the spread of fire.

5. Future catchment climate projections

This section presents future catchment-specific precipitation, temperature and evaporation projections. These variables are essential to explain changes in lake level, cultivation and fire frequency changes (sections 7-8; annex 1). First the modelling and analytical procedures are described. Thereafter, projections of specific variables are presented and discussed.

5.1 Data and methodology

Daily output from RCA4 regional climate model developed at the Swedish Meteorological and Hydrological Institute (SMHI) (Stranberg et al., 2014 and references therein) driven by the Max Planck Institute for Meteorology model MPI-ESM-LR (Popke et al., 2013) has been used (hereafter SMHI-MPI). The model has been developed within the framework of CORDEX (Coordinated Regional Climate Downscaling Experiment; http://www.meteo.unican.es/en/projects/CORDEX) and specifically its European component (EURO-CORDEX; Jacob et al., 2014). SMHI-MPI has a horizontal resolution of about 12 km × 12 km.

With the Intergovernmental Panel on Climate Change's (IPCC) release of the Fifth Assessment Report (AR5; IPCC, 2013) the so-called representative concentration pathway (RCP) scenarios have been introduced which specify GHG concentrations and corresponding emission pathways for several radiative forcing targets.

The **RCP 4.5** was developed by the GCAM modeling team at the Pacific Northwest National Laboratory’s Joint Global Change Research Institute (JGCRI) in the United States. It is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshooting the long-run radiative forcing target level (Clarke et al. 2007; Smith and Wigley 2006; Wise et al. 2009). This scenario also suggests that various climate policies are implemented (Thomson et al., 2011).

The **RCP 8.5** was developed using the MESSAGE model and the IIASA Integrated Assessment Framework by the International Institute for Applied Systems Analysis (IIASA), Austria. This RCP is characterized by increasing greenhouse gas emissions over time, representative of scenarios in the literature that lead to high greenhouse gas concentration levels (Riahi et al., 2007). It represents a future state where no climate policies aiming at the reduction of GHG emissions are implemented (van Vuuren et al., 2011).

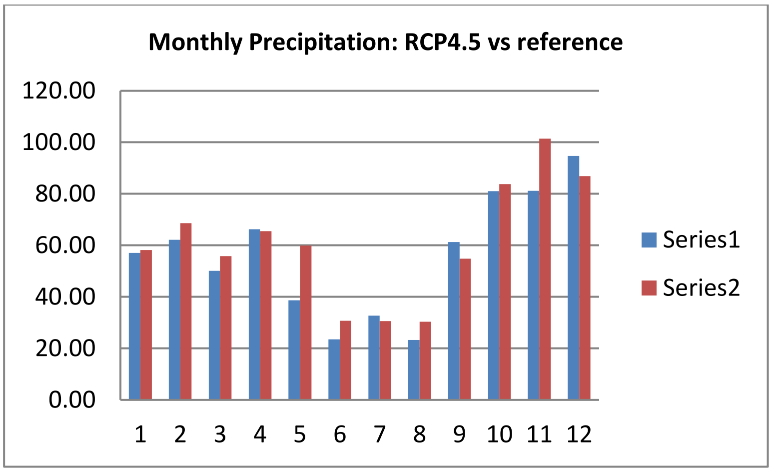
Model output of mean daily (maximum) temperature, and daily total precipitation and evaporation for the closest model grid point to the study region of Prespa were extracted. Future projections, covering 2071–2100 (hereafter distant future) under the new IPCC RCP4.5 and RCP8.5 scenarios, were compared to 1971–2000 observational data (reference period). Future projections were adjusted with the delta-change method (Räty et al. 2014) to derive corrected records that drive temperature models and are comparable to lake level thresholds. Non-parametric boot-strap testing (with confidence intervals at the 95th percentile) were employed (for its robustness) to detect statistically significant changes between the data-sets from the reference period and the distant future (Diciccio 1996, Varotsos *et al*. 2013).

5.2 Results

Analyses on trends for the current and future climate are presented below. Precipitation data were analysed per Oct-Sep (12 month) wet-dry cycle, as is customary for hydrological records in the Mediterranean and for river basins with significant snowfall (Dai *et al*. 2004, Tsakiris *et al*. 2007).

5.2.1 Precipitation

Precipitation is set to decrease in the distant future. Under the RCP4.5 scenario, precipitation is decreasing most in late spring and summer compared to the reference period (Fig. 5.1a), while under RCP8.5 all months except for February show a decline (Fig. 5.1b). When the average precipitation and percentiles of the two model scenarios are compared to the reference period, there is a difference in all statistical targets (Table 5.1). However, statistical analyses (Table 5.3) show that the change in average hydro-yearly precipitation (i) under scenario RCP4.5 is not statistically significant, and (ii) under scenario RCP8.5 is statistically significant. The changes of all percentiles, under both scenarios, are statistically significant except for the 95th percentile of RCP8.5. However, percentiles do not decrease equally; rainfall during years with high precipitation (>75th percentile) decreases with a greater amount than rainfall during years with low precipitation (<25th percentile).



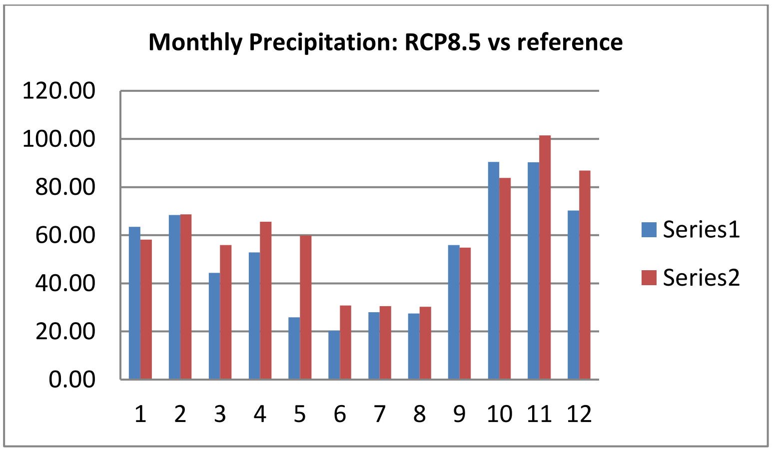


Figure 5.1 Monthly precipitation RCP4.5 / 8.5 scenarios (2071-2100) vs reference period (1971-2000)

Interestingly, there is a different picture when future precipitation is broken down into a wet- and dry period (Table 5.2): now the decrease in precipitation is only statistically significant for the dry season under RCP8.5 (Table 5.3). The average total precipitation during the wet season is even the same under both future climate scenarios (Table 5.2).

	control	RCP45	RCP85
average	724,16	672,19	637,77
5th	517,70	437,16	409,49
10th	574,60	491,15	464,02
15th	589,90	505,55	481,25
20th	622,20	552,02	530,70
25th	633,80	589,58	562,51
75th	818,60	770,11	735,88
80th	825,20	791,13	744,27
85th	841,40	834,46	767,03
90th	868,00	858,20	804,44
95th	972,10	910,25	853,35

Table 5.1 Precipitation (mm) averages and percentiles for the reference period (1971-2000) and RCP4.5 / 8.5 scenarios (2071-2100)

A	control	RCP45	RCP85
average	455,79	427,07	427,75
5th	284,40	259,75	268,25
10th	310,80	295,40	288,20
15th	355,10	326,50	333,56
20th	377,60	352,00	355,90
25th	390,70	362,45	370,75
75th	518,00	494,50	481,75
80th	529,60	508,40	485,40
85th	544,60	513,55	518,20
90th	566,80	545,50	541,60
95th	635,90	578,40	593,70

B	control	RCP45	RCP85
average	268,37	245,12	210,02
5th	142,60	109,99	94,46
10th	179,00	150,10	125,80
15th	194,30	160,02	129,36
20th	210,40	164,80	141,66
25th	233,50	185,68	151,18
75th	303,40	304,21	260,26
80th	333,40	319,46	272,40
85th	340,40	328,90	294,81
90th	362,40	360,70	311,98
95th	368,70	380,95	327,10

Table 5.2 Wet season (a) and dry season (b) precipitation (mm) averages and percentiles for the reference period (1971-2000) and RCP4.5 / 8.5 scenarios (2071-2100)

Record	**Scenario**		**Bootstrap analyses**			
			c.i. min	change	c.i. max	*significant*
Annual precipitation	RCP4.5	mean (absolute, mm)	-63	-55	-48	*y*
		5th percentile	-2	-1	-1	*y*
		10th percentile	-3	-2	-1	*y*
		15th percentile	-3	-2	-1	*y*
		20th percentile	-4	-2	-1	*y*
		25th percentile	-4	-3	-2	*y*
		75th percentile	-9	-7	-5	*y*
		80th percentile	-9	-7	-4	*y*
		85th percentile	-7	-4	-1	*y*
		90th percentile	-7	-4	0	
		95th percentile	-12	-6	-1	*y*
	RCP8.5	mean (absolute, mm)	-98	-89	-80	*y*
		5th percentile	-3	-2	-1	*y*
		10th percentile	-4	-3	-2	*y*
		15th percentile	-5	-4	-3	*y*
		20th percentile	-7	-5	-4	*y*
		25th percentile	-7	-6	-5	*y*
		75th percentile	-13	-10	-8	*y*
		80th percentile	-15	-11	-7	*y*
		85th percentile	-11	-8	-4	*y*
		90th percentile	-9	-7	-4	*y*
		95th percentile	-13	-7	-2	*y*
Wet season precipitation (Oct-Mar)	RCP4.5	mean (absolute, mm)	-68	-28	12	
	RCP8.5	mean (absolute, mm)	-74	-28	13	
Dry season precipitation (Apr-Sep)	RCP4.5	mean (absolute, mm)	-63	-25	14	
	RCP8.5	mean (absolute, mm)	-91	-58	-22	*y*
Hydro-yearly precipitation (Oct-Sep)	RCP4.5	mean (absolute, mm)	-115	-52	14	
		5th percentile	-2	-1	-1	*y*
		10th percentile	-3	-2	-1	*y*

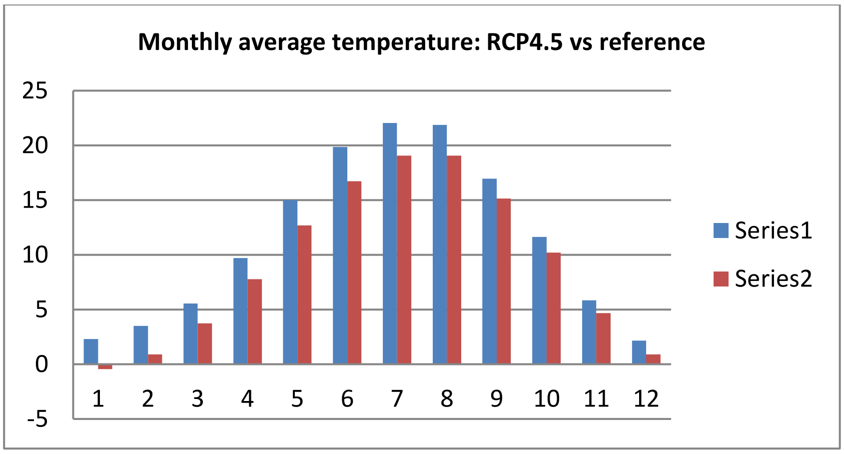
		15th percentile	-3	-2	-2	*y*
		20th percentile	-3	-2	-1	*y*
		25th percentile	-3	-3	-2	*y*
		75th percentile	-9	-7	-5	*y*
		80th percentile	-9	-6	-3	*y*
		85th percentile	-8	-4	0	
		90th percentile	-9	-5	0	
		95th percentile	-13	-8	-2	*y*
	RCP8.5	mean (absolute, mm)	-145	-86	-24	*y*
		5th percentile	-3	-2	-1	*y*
		10th percentile	-5	-4	-2	*y*
		15th percentile	-6	-4	-3	*y*
		20th percentile	-5	-4	-3	*y*
		25th percentile	-6	-5	-4	*y*
		75th percentile	-14	-11	-8	*y*
		80th percentile	-14	-10	-7	*y*
		85th percentile	-15	-12	-9	*y*
		90th percentile	-13	-10	-7	*y*
		95th percentile	-9	-4	1	
Open surface (Lake) evaporation	RCP4.5	mean (absolute, mm)	59,3	59,5	59,8	*y*
	RCP8.5	mean (absolute, mm)	129,0	129,3	129,5	*y*
Temperature (average, monthly)	RCP4.5	mean (absolute, °C)	2,169	2,171	2,174	*y*
	RCP8.5	mean (absolute, °C)	4,708	4,713	4,714	*y*
Temperature (average maximum, monthly)	RCP4.5	mean (absolute, °C)	2,343	2,346	2,349	*y*
		5th percentile	2,050	2,260	2,480	*y*
		10th percentile	2,240	2,400	2,530	*y*
		15th percentile	2,280	2,430	2,580	*y*
		20th percentile	2,170	2,380	2,550	*y*
		25th percentile	1,980	2,090	2,210	*y*
		75th percentile	2,610	2,670	2,730	*y*
		80th percentile	2,820	3,000	3,160	*y*
		85th percentile	2,970	3,050	3,120	*y*
		90th percentile	3,020	3,070	3,110	*y*
		95th percentile	3,010	3,050	3,100	*y*

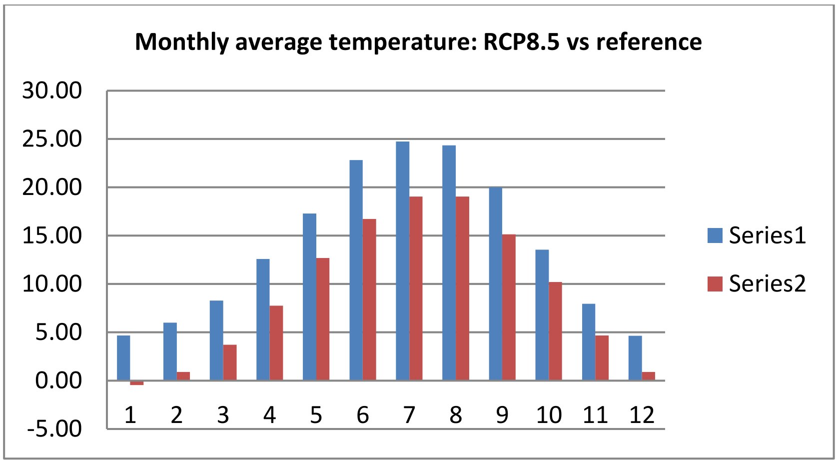
	RCP8.5	mean (absolute, °C)	5,098	5,102	5,106	*y*
		5th percentile	4,880	5,060	5,230	*y*
		10th percentile	4,980	5,120	5,240	*y*
		15th percentile	4,980	5,120	5,250	*y*
		20th percentile	4,890	5,070	5,240	*y*
		25th percentile	4,700	4,830	4,960	*y*
		75th percentile	5,610	5,710	5,800	*y*
		80th percentile	5,760	5,940	6,110	*y*
		85th percentile	5,730	5,830	5,910	*y*
		90th percentile	5,650	5,750	5,860	*y*
		95th percentile	5,610	5,720	5,830	*y*

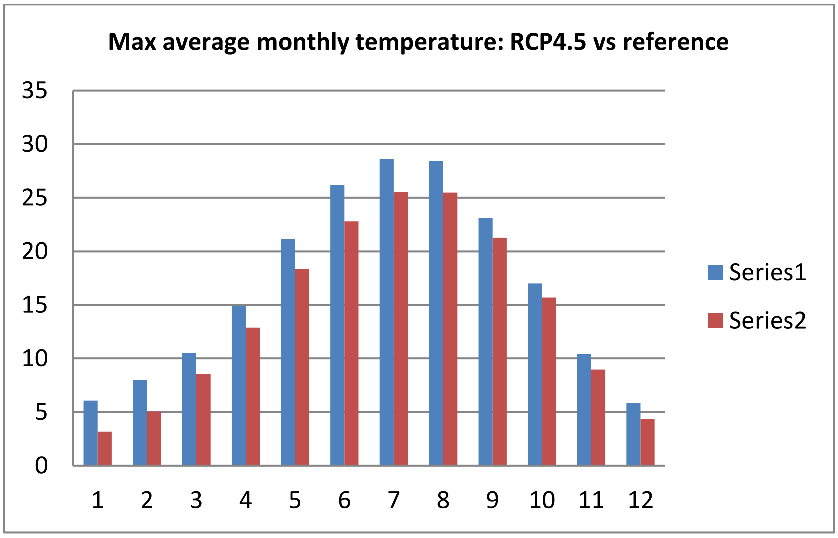
Table 5.3 Bootstrap statistical analyses: results for precipitation, evaporation and temperature (reference period (1971-2000) vs RCP4.5 / 8.5 scenarios (2071-2100))

5.2.2 Temperature

Monthly average and maximum temperatures are projected to rise during all months in the distant future. The monthly increases under the RCP4.5 scenario are in the order of 1-3 °C; monthly temperature increases under RCP8.5 are with 3-6 °C much larger (Fig. 5.2). Maximum monthly temperatures are set to rise slightly more than average monthly temperatures under both scenarios. When the average temperatures and percentiles of the two model scenarios are compared to the reference period (on an annual basis), there is a difference in all parameters (Table 5.4). The statistical analyses (Table 5.3) indicate that changes in annual average and maximum temperatures are statistically significant under both scenarios, RCP4.5 and RCP8.5. Additionally, the changes in annual maximum temperature percentiles, under both scenarios, are statistically significant. Maximum temperatures increases during (extremely) warm years (>75th percentile) are higher by about 0.5 °C than the maximum temperatures during cooler years (<25th percentile).







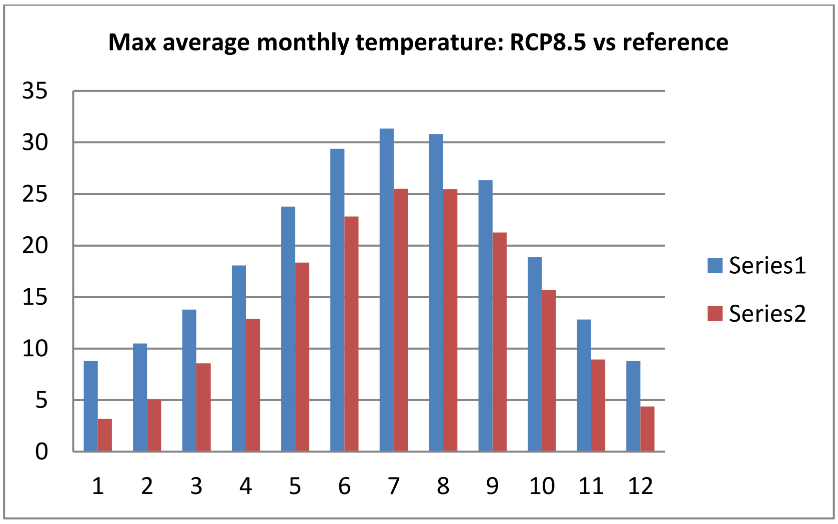


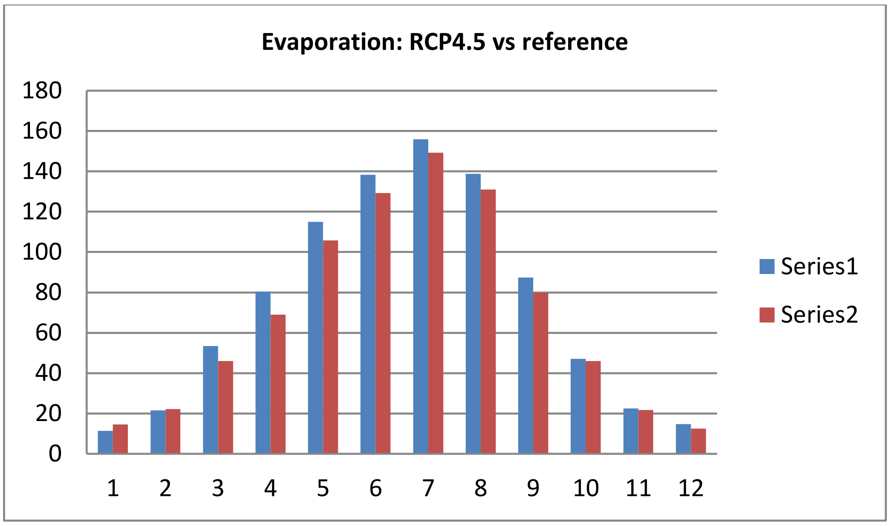
Figure 5.2 Monthly average temperature and monthly average maximum temperature: RCP4.5 / 8.5 scenarios (2071-2100) vs reference period (1971-2000)

A	control	RCP45	RCP85
average	9,20	11,37	13,91
5th	8,36	10,53	13,08
10th	8,46	10,62	13,16
15th	8,58	10,75	13,29
20th	8,67	10,83	13,37
25th	8,71	10,89	13,43
75th	9,60	11,76	14,32
80th	9,70	11,87	14,41
85th	9,76	11,92	14,46
90th	10,03	12,20	14,73
95th	10,42	12,60	15,13
B	control	RCP45	RCP85
average	14,34	16,68	19,44
5th	13,51	15,86	18,62
10th	13,59	15,94	18,69
15th	13,63	15,97	18,73
20th	13,66	16,01	18,77
25th	13,73	16,08	18,83
75th	14,79	17,13	19,90
80th	14,94	17,29	20,04
85th	15,12	17,46	20,21
90th	15,35	17,69	20,45
95th	15,72	18,06	20,81

Table 5.4 Temperature (mm) averages and percentiles for mean temperature (A) and maximum temperature (B): reference period (1971-2000) and RCP4.5 / 8.5 scenarios (2071-2100)

5.2.3 Evaporation

Evaporation is set to increase in the distant future. Under the RCP4.5 scenario, evaporation is increasing from spring to summer, compared to the reference period (Fig. 5.3). Under RCP8.5 all seasons except for winter show an increase (Fig. 5.3). When the average annual evaporation and percentiles of the two model scenarios are compared to the reference period, there is a difference in all parameters (Table 5.5). The statistical analyses (Table 5.3) show that the increases in evaporation are statistically significant under both scenarios, RCP4.5 and RCP8.5. Annual open surface evaporation from the lake increases by 60 mm (RCP4.5) to 129 mm (RCP8.5) by the end of this century.



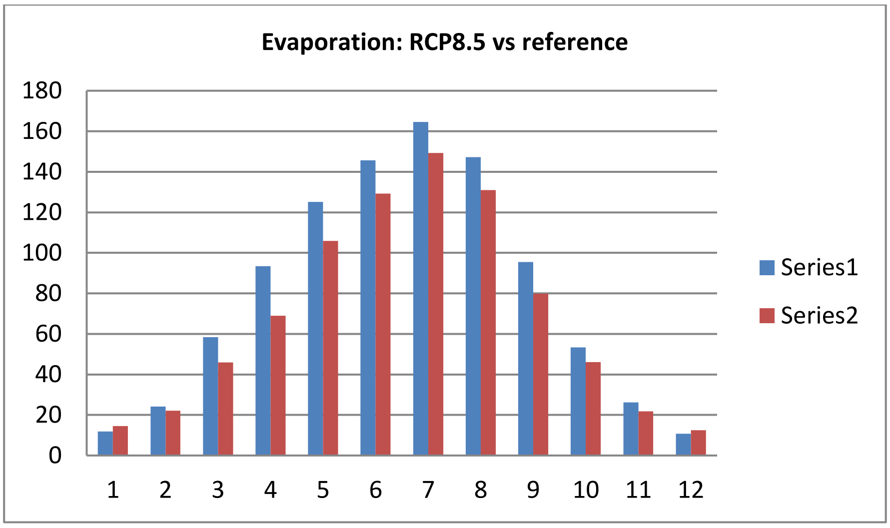


Figure 5.3 Monthly average evaporation (mm): RCP4.5 / 8.5 scenarios (2071-2100) vs reference period (1971-2000)

	control	RCP45	RCP85
average	826,96	886,49	956,24
5th	670,12	729,11	798,85
10th	769,92	829,43	899,17
15th	802,12	861,83	931,57
20th	804,32	863,11	932,85
25th	807,40	866,83	936,57
75th	867,80	927,43	997,17
80th	869,60	929,83	999,57
85th	876,00	935,95	1005,69
90th	898,64	957,35	1027,09
95th	900,36	960,23	1029,97

Table 5.5 Evaporation (lake surface; in mm) averages and percentiles for the reference period (1971-2000) and RCP4.5 / 8.5 scenarios (2071-2100)

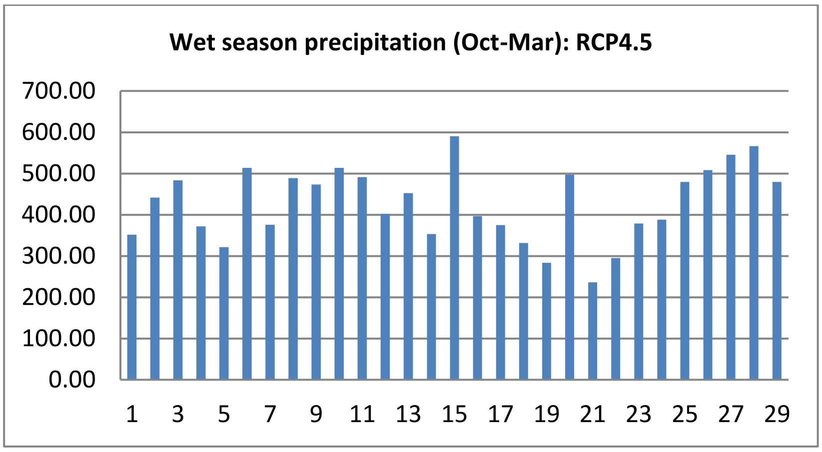
6. Climate change impacts on Lake Lesser Prespa

This section explores the impacts of the projected future changes in catchment climate (section 5) on lake level lowstands, shoreline positions, drought, and lake temperature. For a full discussion on the methods, approaches and thresholds, see sections 3 and 4.

6.1 Lake level lowstands

The impact of projected precipitation changes on lake level is based on the application of wet season precipitation thresholds that are associated with specific lake level analogues (section 3.3). Precipitation projections of both scenarios (RCP 4.5/8.5) for the wet season do not record a statistically significant difference from the reference period (section 5.2.1).

[A] Significant lake level lowstands (water levels <850 m for 12 months of the hydrological year ***and*** below 896,6 m for 5 months and more) occur when the 6-month wet season precipitation at the end of March is **below 370 mm**. Five years (1976, 1989-90, 1992-93) in the reference period (1972-2000) fall below this threshold. For scenarios RCP4.5 and RCP8.5, seven years (2072, 2076, 2085, 2089-90, and 2092-93) out of 29 (2072-2100) fall below this threshold (Fig. 6.1).



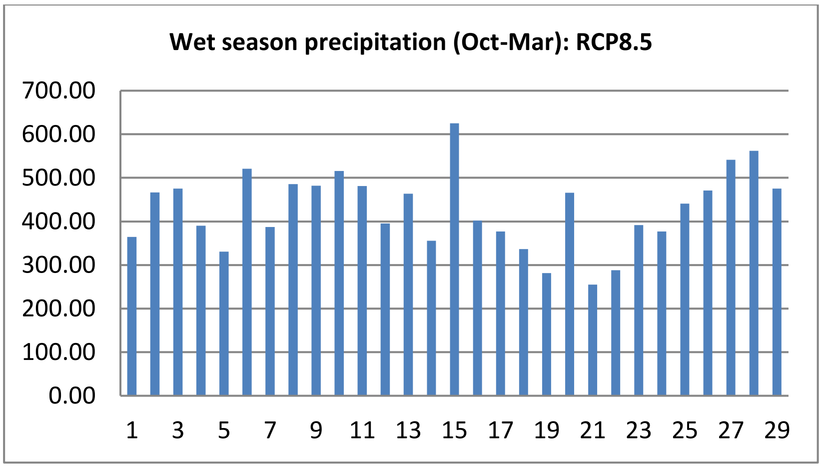


Figure 6.1 Wet season precipitation (in mm), for scenarios RCP4.5 and RCP8.5 (years 2072-2100)

[B] Extreme lake level lowstands (water level at or below 849 m for several months and below 849.6 m for at least one hydro-years) occur when **two subsequent wet seasons receive less than 370 mm** of precipitation each (measured at the end of March). This situation happens twice over the reference period (1989-90, 1992-93). RCP4.5 and RCP8.5 scenarios also show two extreme lake level lowstands (2089-90, 2092-93).

[C] Water levels below 850 m for 7 months or more occur when the wet season precipitation is **below 415 mm and above 370mm**. Seven years (1972, 1975, 1978, 1985, 1988, 1994-95) in the reference period (1972-2000) fall within this threshold. For scenarios RCP4.5 and RCP8.5, seven years (2075, 2078, 2083, 2087-88, and 2094-95) out of 29 (2072-2100) fall within this threshold.

[D] Lake highstands (water levels above 850 m for the entire hydro-year) occur when the wet season precipitation by the end of March is **above 560 mm**. This situation happens thrice over the reference period (1986, 1998-99). RCP4.5 and RCP8.5 scenarios show wet season precipitation associated with two lake level highstands (2086, 2099).

There appears to be no significant change in future lake level lowstands and highstands, based on wet season precipitation thresholds. This is in line with expectations, as there is no statistically significant change in wet season precipitation under both scenarios (RCP4.5 and RCP8.5). Based on these impact analyses, shoreline fluctuations are expected to remain approximately similar to the reference period. Such long-term stabilization of shorelines is unprecedented in the observational record. The sluice will be entirely closed for at least half of the future period (combined years for thresholds A and C is 14 years), while it will be fully open for only two highstand years (threshold D). This implies that seasonal water level fluctuations will be strongly reduced and seasonal peak levels will be earlier in season (March-April), due to the sluice operation (section 2.5).

6.1.1 Lake level analogues: further considerations

Subtle changes in future precipitation patterns may suppress water level during lowstand-years further than our estimates above show. Specifically, hydro-yearly and dry season precipitation under scenario RCP8.5 are statistically different from the reference period. Secondly, all hydro-yearly precipitation percentiles show a statistically significant shift to decreasing rainfall under both scenarios (Table 5.2). Practically, this means that average wet season rainfall **below the lowstand threshold precipitation values** is less under both future scenarios than over the reference period.

Lake level analogues and threshold values furthermore implicitly assume that other hydrological parameters remain stable. If water abstraction from the lake, shallow groundwater or local streams (that discharge in the lake) increases in the future, lake lowstands will become more severe (falling deeper and lower below 849 m). Furthermore, the precipitation-runoff relationship may change, for example, if rainfall events become more intense as projected (IPCC 2013). This may lead to a more effective water transfer to the lake, and less evapotranspiration, thus increasing average water level. Finally, future lake surface evaporation is set to increase under all scenarios (section 5.2.3). However, the increase in evaporation under scenarios RCP4.5/8.5 is in the order of 3 x 10^6 m^3 and 7 x 10^6 m^3, respectively. This may decrease seasonal peak lake levels in the order of 0,05 m and 0,13 m, respectively.

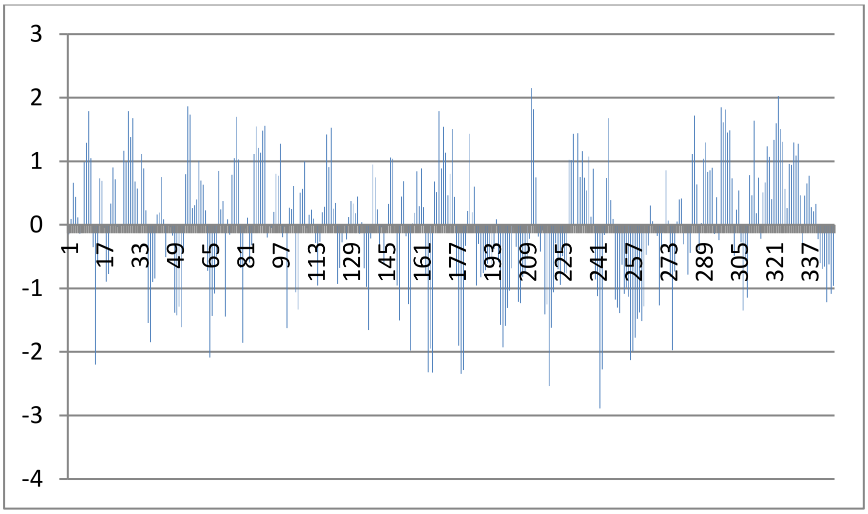
On balance, it is likely that (extreme) lowstand events become more frequent in the distant future, given the above uncertainties.

6.2 Droughts

The pattern of drought in the distant future, based on precipitation under scenarios RCP4.5/8.5, has been calculated with the SPI (see section 3.3 for a description of the methodology). SPI values are based on the time-series 2071-2100, and values are not directly comparable to the reference period, as they are normalized against different time-series.

SPI-3, -6, -9, -12 and -24 were calculated for both climate scenarios. The pattern of dry- and wet periods for scenarios RCP4.5 (Fig. 6.2) and RCP8.5 (Fig. 6.3) are very similar. This is no surprise given the very similar future precipitation patterns under both scenarios (section 5.2.1). Statistically, only RCP8.5 hydro-annual and dry-season precipitation is significantly different from the reference period; wet season precipitation is not. This suggests that shorter term SPI values (-3 to -9) at the end of the wet season (around March) are not statistically different from the reference period, while long-term SPI values and the short-term SPI values at the end of the dry season are statistically different from the reference period.

Comparison of the percentiles of both scenarios with the reference period may be more revealing about the changing nature of wet- and dry periods (Table 5.1, section 5.2.1). Years that are characterized as wet (hydro-annual precipitation above the 75th percentile) and years characterized as dry (hydro-annual precipitation above the 25th percentile) receive both less rainfall under RCP4.5/8.5 compared to the reference period. For wet years this reduction is larger than for dry years. This implies that “extreme lake lowstand years” (water level at or below 849 m for several months and below 849.6 m for at least one hydro-years; section 6.1) receive less precipitation than the reference period. Consequently, lake level may fall deeper than the 848.5 m registered over the reference period (section 2.5).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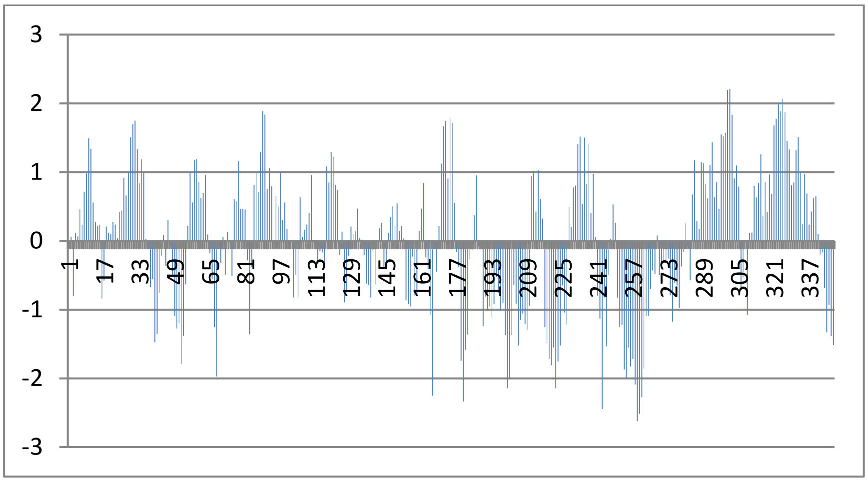
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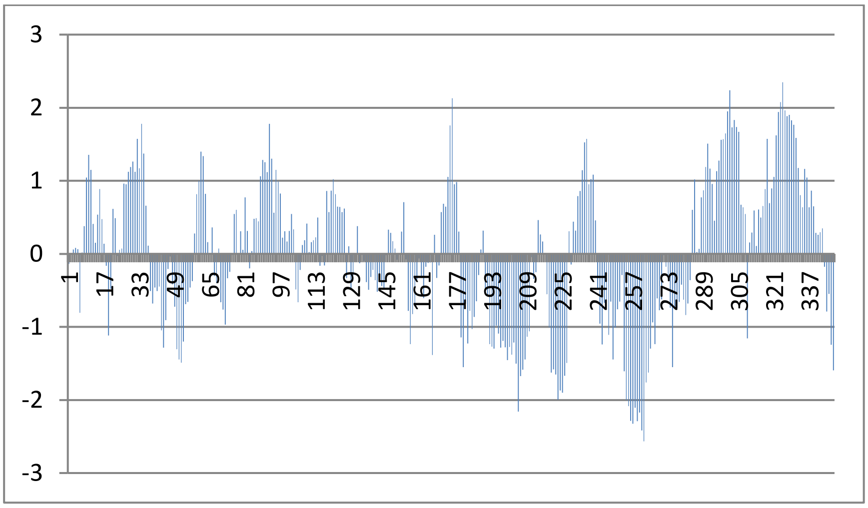
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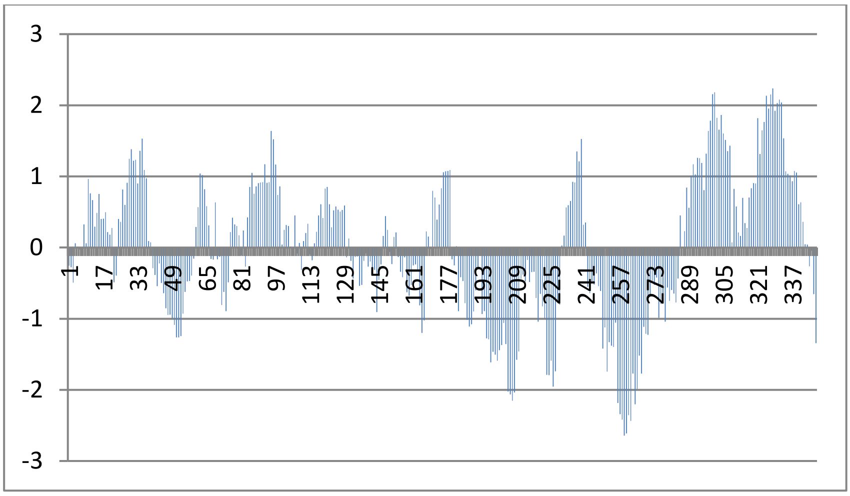

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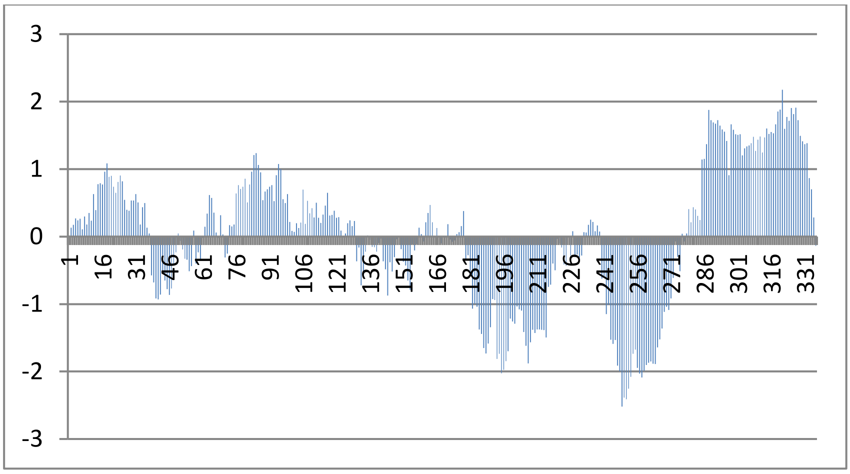

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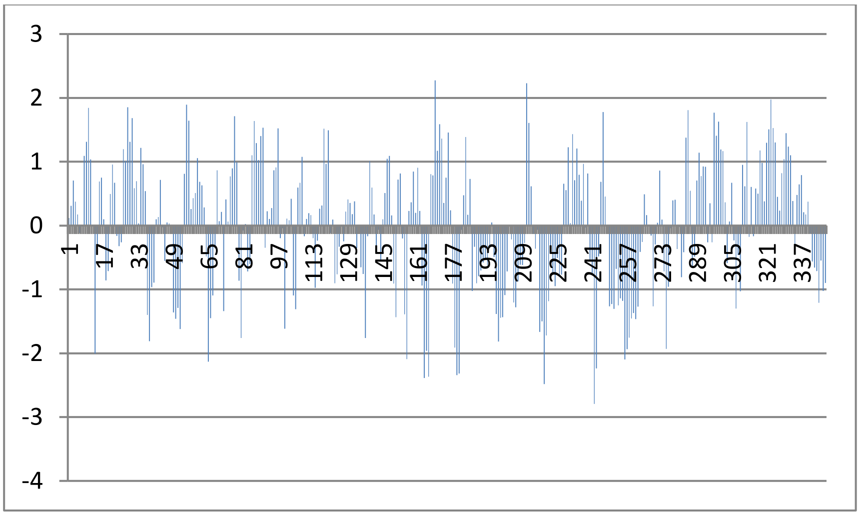
Figure 6.2 Wet/dry periods for the future time-series 2071-2100 under scenario RCP 4.5: SPI-3 (a), SP-6 (b), SPI-9 (c), SPI-12 (d) and SPI-24 (e)



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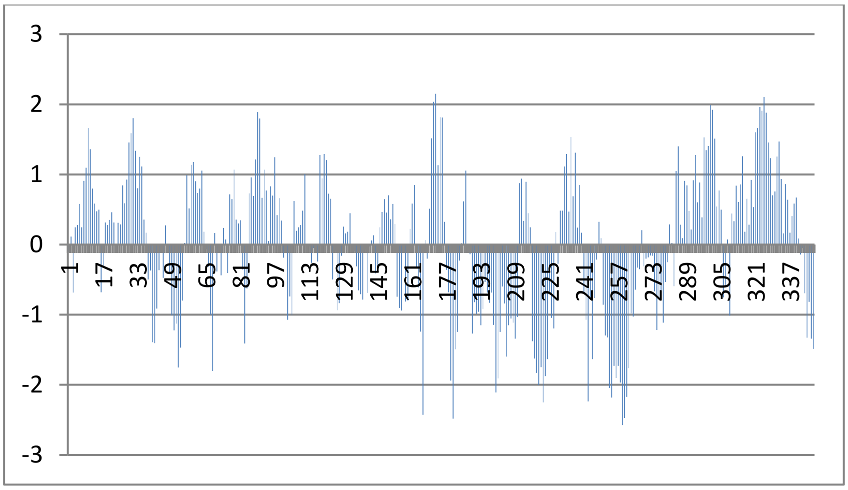
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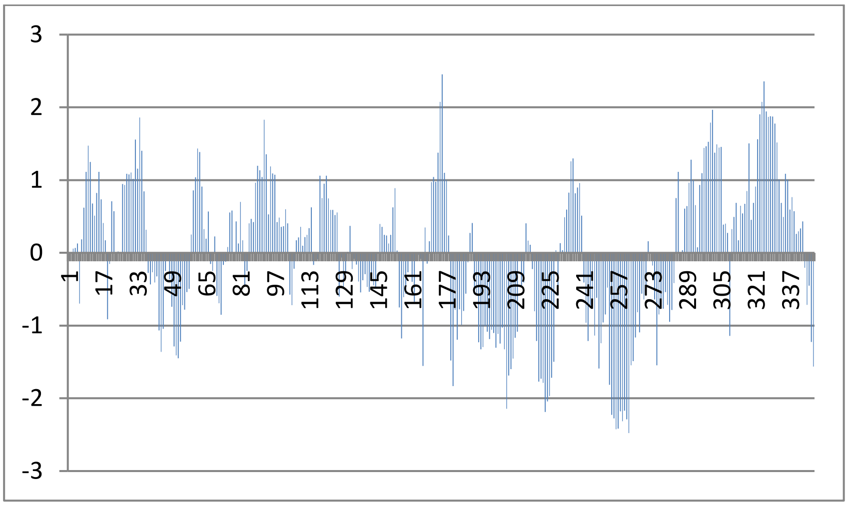
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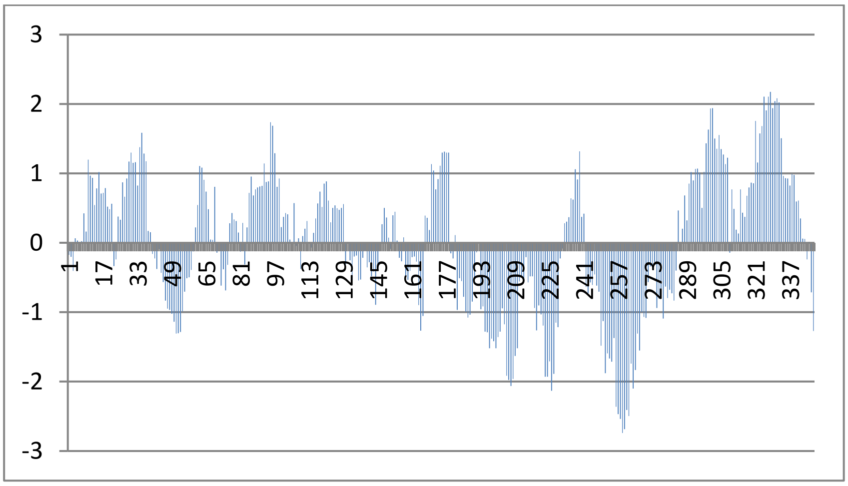
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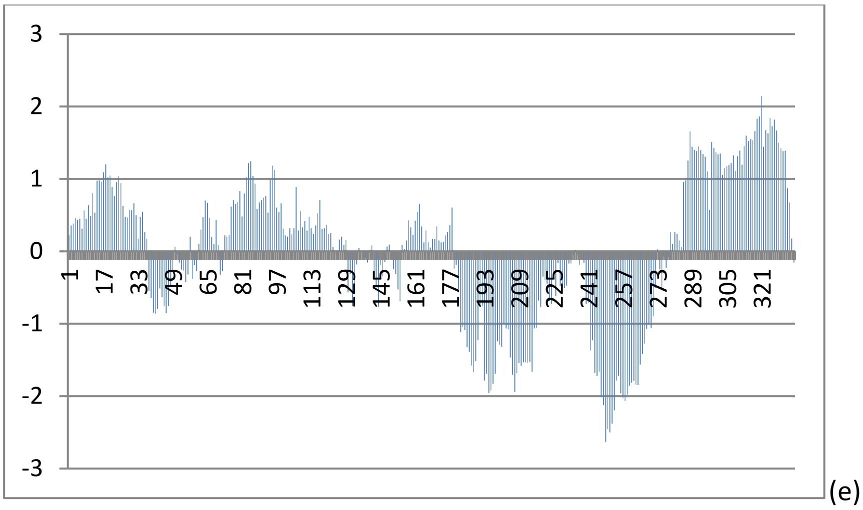

Figure 6.3 Wet/dry periods for the future time-series 2071-2100 under scenario RCP 8.5: SPI-3 (a), SP-6 (b), SPI-9 (c), SPI-12 (d) and SPI-24 (e)

6.3 Lake temperatures

Lake temperatures in the distant future have been based on the linear correlation procedure between maximum air temperature and lake temperature, outlined in section 3.4. These temperatures were found to be statistically significant (95th percentile; bootstrap confidence interval 0.973 – 0.982) and highly correlated (r=0.978; Figure 3.6). The relationship can be described by the following formula, where (y) is monthly lake surface temperature and (x) is monthly maximum air temperature: $y = 0.9924x + 0.8762$. This correlation has been used to estimate future lake temperature based on model projections of air temperature.

Temperatures under both scenarios RCP4.5 and 8.5 show statistically significant, large increases (section 5.2.2). The large increases are reflected in the lake surface temperature projections (Fig. 6.4). The monthly temperature rises are of the same order as the maximum air temperature increases, which is as expected given the linear correlation between the parameters.

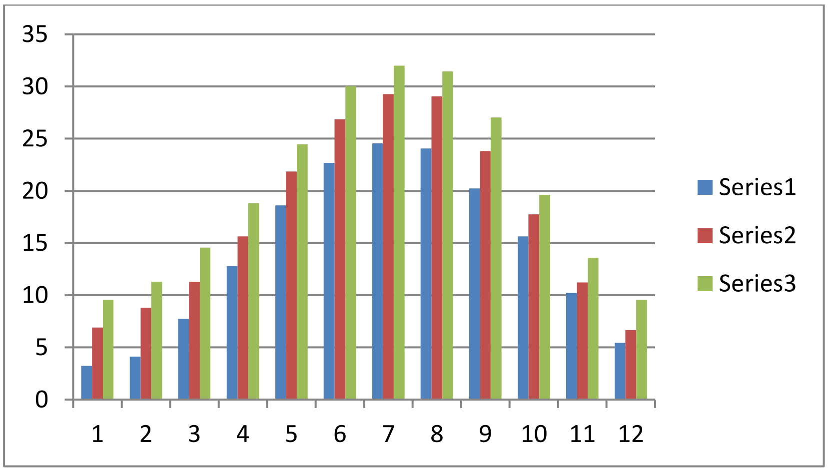

Figure 6.4 Monthly lake surface temperatures: reference period (series 1) and projections (series 2: RCP4.5, series 3: RCP8.5)

7. Fire Weather Index

To assess fire risk around Prespa lakes, the Canadian Fire Weather Index (FWI) was used. Present day simulations covering the period 1971-2000 are used here as reference for comparison with future projections for the periods 2031-2060 (hereafter near future) and 2071-2100 (hereafter distant future) under the new IPCC RCP4.5 and RCP8.5 scenarios.

Model output of mean daily maximum temperature and relative humidity, wind speed and daily total precipitation for the closest model grid point to the study region of Prespa were extracted (SMHI-MPI model; section 5.1) and daily FWI values were calculated. Analysis on trends and critical FWI threshold values for the current and future climate are presented here.

7.1 FWI methodology

The computer model used to calculate FWI is non-dimensional, based on physical processes and has been used at several locations, including the Mediterranean Basin (e.g. Moriondo et al., 2006, Carvalho et al., 2008; Dimitrakopoulos et al., 2011; Giannakopoulos et al., 2012; Karali et al. 2014); indeed, since 2007 the FWI has been adopted at the EU level by the European Forest Fire Information System (EFFIS) of the Joint Research Centre of the European Commission. This was done following a test phase of 5 yr, during which different fire danger methods were implemented in parallel by the EFFIS, until the FWI was selected as the preferred method to assess the fire danger level in a harmonized way throughout Europe. Thus, it seems a sensible basis for exploring the mechanisms of fire risk and fire risk changes around Prespa lakes, in particular. In Table 7.1, the fire danger levels according to EFFIS classification are presented.

Table 7.1: FWI EFFIS classification

FWI classes	FWI ranges (upper bound excluded)
Very Low	<5.2
Low	5.2-11.2
Moderate	11.2-21.3
High	21.3-38.0
Very high	38.0-50.0
Extreme	≥50.0

The FWI system provides numerical ratings of relative fire potential based solely on weather observations (van Wagner, 1987). The meteorological inputs to the FWI system are noon local time values of temperature, air relative humidity, wind speed and precipitation during the previous 24 hours.

The FWI system consists of six standard components each measuring a different aspect of fire danger. The first three primary sub-indices are fuel moisture codes and are numerical ratings of the moisture content of litter and other fine fuels (FFMC), the average moisture content of loosely compacted organic layers of moderate depth (DMC) and the average moisture content of deep, compact organic layers (DC). Moisture code values for the current day are calculated from the day's observed weather and the previous day's fuel moisture code values. The two intermediate sub-indices (ISI, BUI) are fire behaviour indices.

The Initial Spread Index (ISI) is a numerical rating of the expected fire rate of spread. It combines the effect of wind and FFMC on rate of spread without the influence of variable quantities of fuel. The Buildup Index (BUI) is a numerical rating of the total amount of fuel available for combustion that combines the DMC and the DC. The resulting index is the Fire Weather Index (FWI) which combines ISI and BUI. FWI represents the frontal fire intensity and is used to estimate the difficulty of fire control.

7.2 FWI Results

In **Error! Reference source not found.**, summer FWI trends up to the end of the century are presented. A clear increasing trend is evident for both scenarios. Under the moderate RCP4.5, a weaker trend is evident, while under the more aggressive RCP8.5 scenario, the upwards trend becomes more significant. The difference between the two scenarios starts building up after the year 2040 mark and reaches its highest value towards the end of the century.

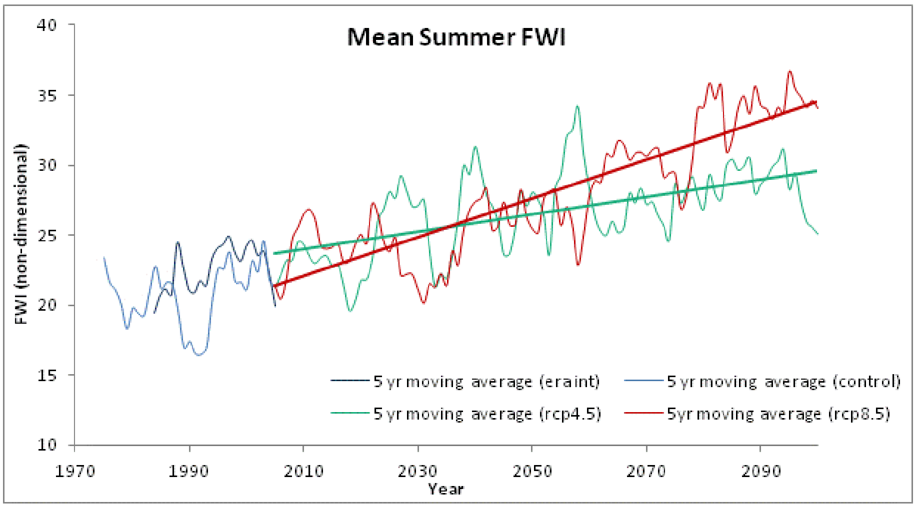

Figure 7.2: Five year moving average of modeled FWI values for the current climate and their trends until the end of the century under RCP4.5 and 8.5.

According to SMHI-MPI, mean summer FWI for current climate conditions is 21 (moderate risk) (Figure 7.3). In the near future a statistical significant (c.l 95%) increase of 7 units is projected under RCP4.5, while, for the distant future, mean FWI values remain essentially the same. As described in the trends above, mean summer FWI under RCP8.5 for the near future climate is similar to the moderate scenario. For the distant future, the increase is pronounced and FWI mean reaches the value of 33 (high risk) by the end of the century.

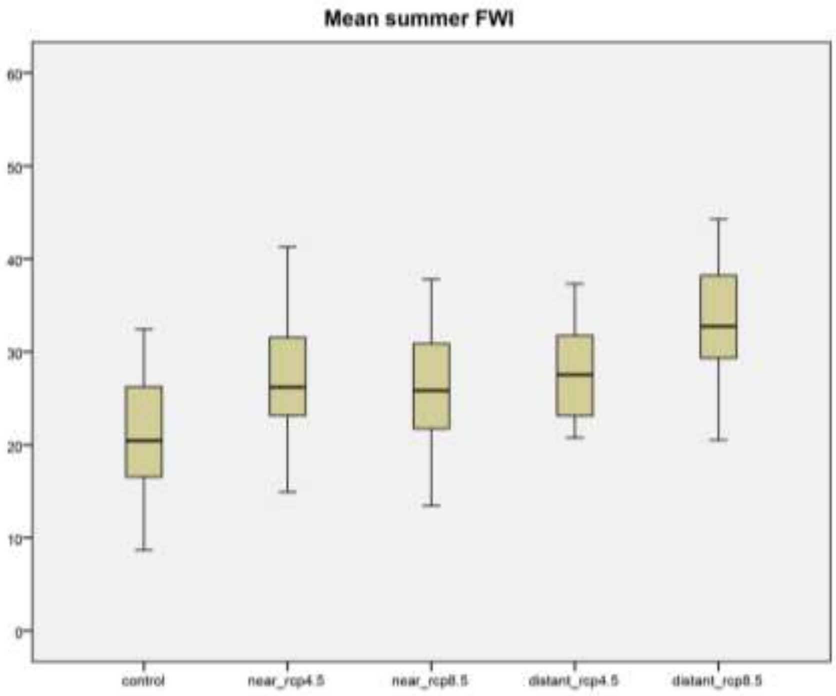

Figure 7.3: Box and whisker plots for mean summer FWI for Prespa for the control period (1971-2000) as well as the near (2031-2060) and distant (2071-2100) future under RCP4.5 and 8.5.

Figure 7.4 shows the inter-annual variability of mean monthly FWI values for the control period and future periods under the two RCPs. FWI receives higher values during July and August, as expected, which are, climatologically, the hottest and driest months for the study region. In the near future period, RCP4.5 presents slightly higher summer FWI values compared to RCP8.5. During the summer control period, FWI values range between 11 and 27, while in the near future these values vary from 17 to 32 accordingly. September presents moderate class values according to EFFIS classification, ranging between 19 for the current climate to 21 for the near future climate. In the distant future, mean monthly FWI values for the months between June and September have significantly increased compared to their values in the near future period. It should be noted that for the RCP8.5, the fire season is expected to expand well over June and September in the distant future as FWI enters the high risk EFFIS class.

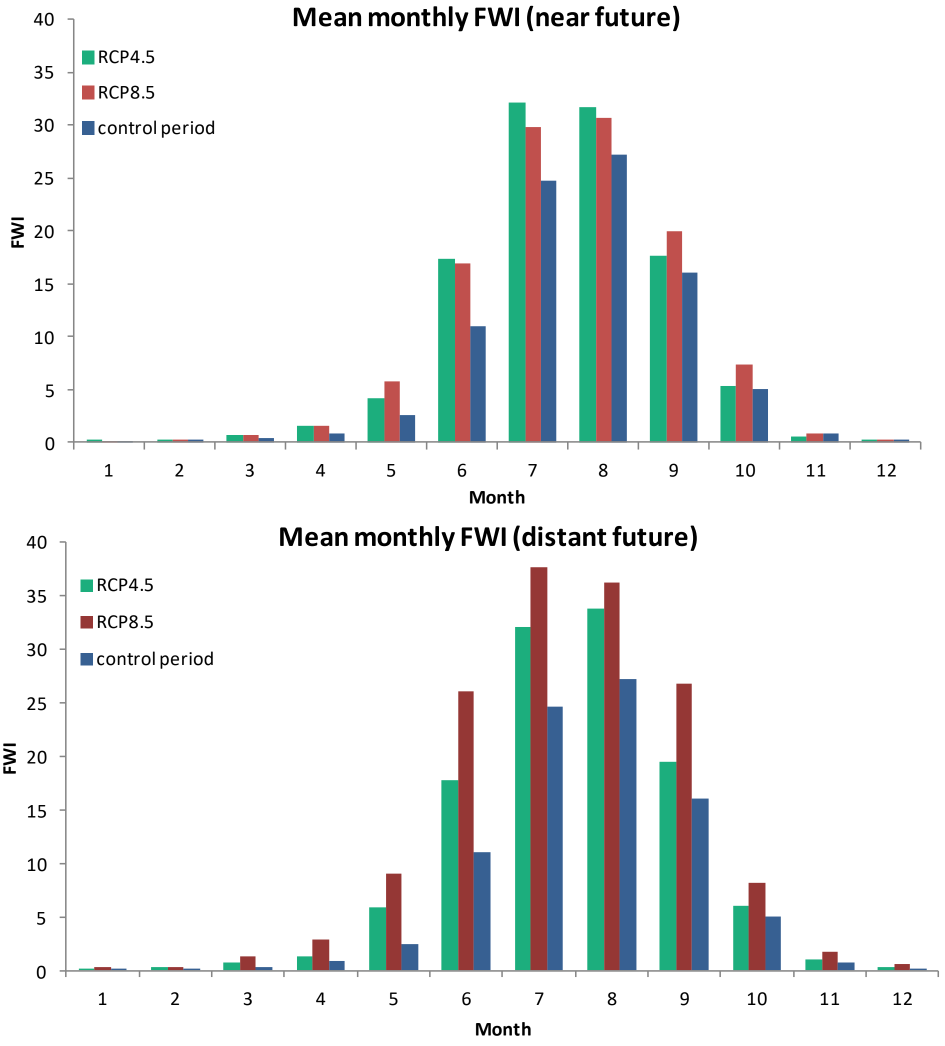

Figure 7.4: Mean monthly FWI values for the control period, near (2031-2060) and distant (2071-2100) future.

Finally, the number of days fire risk exceeds critical thresholds for the study area both for current and future climate is estimated. In the framework of the current study a threshold of FWI>15 was selected as a measure of moderate fire risk in the area of interest and FWI>30 was selected as a measure of high fire risk, in accordance to EFFIS fire danger classification.

According to SMHI-MPI (Figure 7.5), in the current climate (1971-2000) the mean number of days with moderate fire risk reach 80 per year, while the number of high fire risk days is 26. In the near future, the mean number of days with moderate fire risk is expected to be 87 per year and 46 with high fire danger conditions under RCP4.5. Under RCP8.5, 95 moderate fire risk days per year and 20 days with high fire danger are projected.

In the distant future and under RCP4.5 scenario, the number of moderate and high fire risk days are about 94 and 48 per year, respectively. Under the more pessimistic RCP8.5 scenario, 108 days per year with moderate and 39 days per year with high fire risk are expected.

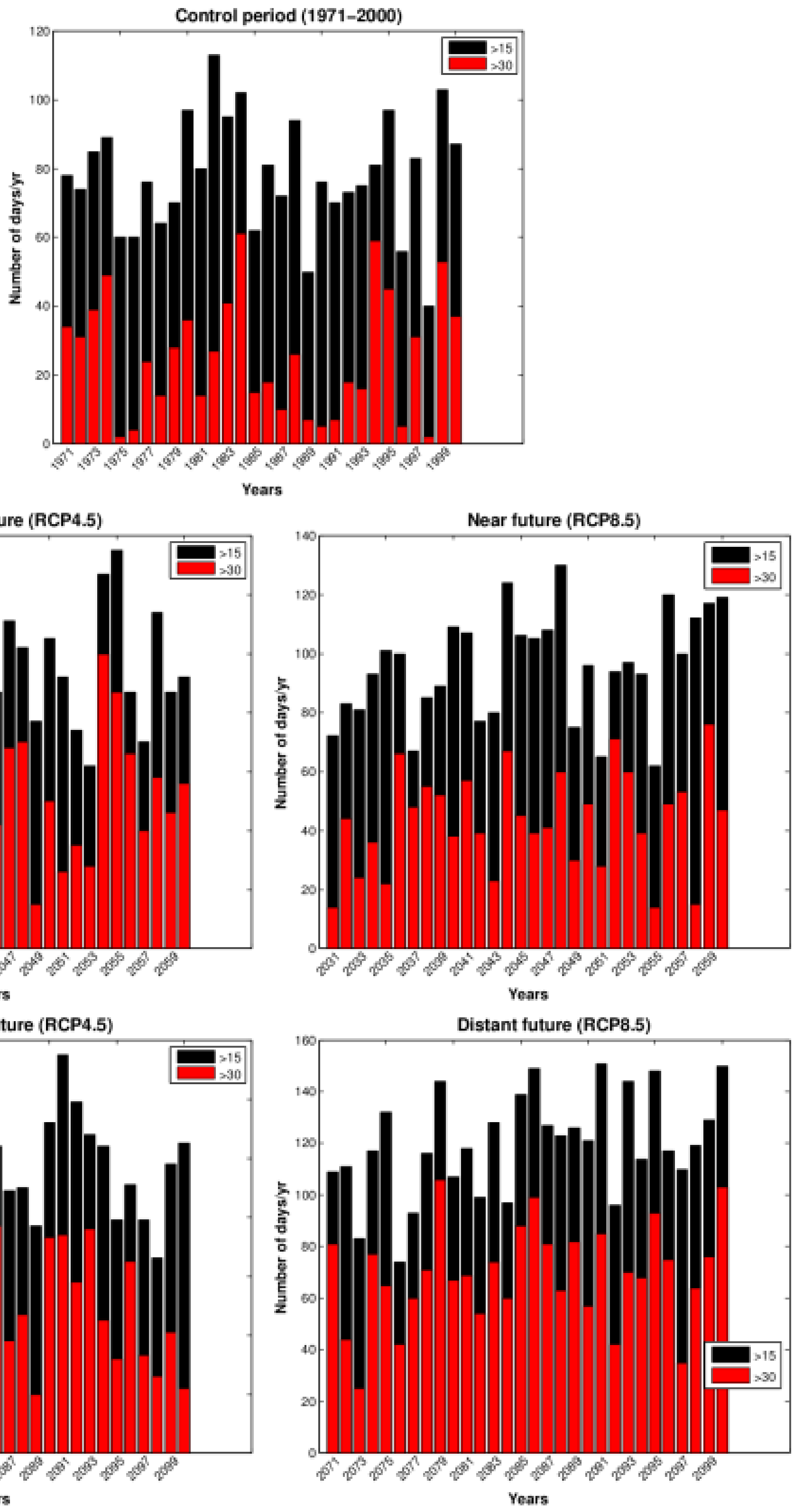

Figure 7.5 Number of days with FWI>15 and FWI>30 for the control period and future periods under RCP4.5 /8.5.

In conclusion, in the future climate, more days with moderate and high fire risk are expected and the fire risk season expands into June and September, changes which are more pronounced under the RCP 8.5 scenario as we approach the end of the century (2071-2100).

8. Vulnerability of shoreline habitats to projected climate change & management recommendations

This section a vulnerability assessments of available fish spawning grounds, bird nesting- and foraging sites around Lesser Prespa Lake under future climate scenarios. These assessments are used to formulate crucial management guidelines regarding the required altitudinal range of future open shallows areas and the location of fire-corridors protecting reedbeds.

8.1 Climate change vulnerability of fish spawning grounds, bird foraging- and nesting sites

Wet meadows and other open shallow areas around the alluvial shorelines of Lesser Prespa Lake constitute important fish spawning grounds and wading-bird foraging areas. Reedbeds that fringe the lake margin form important nesting sites. The main direct impacts posed by climate change to these crucial habitats are related to changes in frequencies/magnitudes of (extreme) lake level lowstands, decreasing seasonal lake level variability and fire-frequency/access changes. Furthermore, lake temperature is directly related fish spawning.

8.1.1 Lake level projections under future climate scenarios

Lake water level fluctuations will not significantly change under future climate scenarios RCP4.5 and RCP8.5 (section 6.1). Only extremely low lake levels may fall below observed analogues, as future years with extremely low rainfall will receive significantly less precipitation. Seasonal and multi-annual water level fluctuations will be similar to the reference period, if there are no large changes in water abstraction and rainfall-runoff relationships (strongly influenced by, for example, land-use, precipitation intensity, and snow-cover).

However, water level fluctuations are strongly influenced by the operation of the sluice-system (2004-2016; section 2.5). Seasonal and multi-annual lake level variations greatly decrease. This leads to flooding of a smaller part of the wet meadows/open areas, and to fixation of the reed-belts within a narrow height-range. Large multi-annual water level fluctuations combined with traditional land-use of the lake margins (that followed lake level movements) led to the removal of nutrients and renewal of reed, while limiting the width of the reedbelt (section 4.3). This likely led to less dense, younger and more species-diverse reedbeds compared to the present situation.

8.1.2 Lake temperature projections

Projections suggest that lake water surface temperatures will increase in line with air temperatures under the two climate scenarios that were analysed (RCP4.5 and RCP8.5; section 6.3). Increasing lake temperatures affect the timing of fish spawning, and thus waterbird forage availability. The duration of the spawning period is related to water temperature. For the Prespa fish population it starts in spring when water temperature (T) is raised to 16 ^{o}C and ends 30 days after T = 18 ^{o}C (Parisopoulos 2007). Given these constraints, fish pawning may occur up to one month earlier (Fig. 6.4) by the end of this century around the shorelines of Lesser Prespa Lake.

Secondly, the increase in temperature may speed-up ecological processes that lead to eutrophication of the lake (Jeppesen *et al*., 2014). Already, there is no significant flow between the lakes and thus less fluxing out of pollutants/nutrients, while fewer nutrients are removed due to the absence of large lake level fluctuations and traditional shoreline vegetation management (section 4.3). Thus many factors combine to increase the pollutant/nutrient concentration of the lake water, amplifying eutrophication and likely affecting reedbed density / species composition.

8.1.3 Changes in future fire frequencies

Observed reedbed fires take mainly place in February and March, under normal to wet conditions (section 4.4). No relationship has been found with drought conditions. Rather, these fires are associated with land-use practices, while their spread may be related to dense presence of continuous reedbeds along the lake shores and in the drainage ditches. Natural barriers that would have hampered the spread of reedbeds fires, in particular channels, have been invaded by reed due to fixation of lake level and hydrological modifications of channels and their discharge.

For the wider catchment, in the future climate, more days with moderate and high fire risk are expected and the fire risk season expands from July to include June and September (section 7). These changes are more pronounced under the RCP 8.5 scenario towards the end of the century (2071-2100). This may suggest that reedbed fires during these months, which are currently rare, may take place in the distant future.

8.2 Management Guidelines

Management guidelines aim to safeguard the availability of foraging/fish-spawning areas and protect the nesting sites of targeted bird species under the lowest possible water levels and intensive future drought/fire conditions. These guidelines take an ecosystems-based approach: by looking at “natural” hydrological cycles and traditional land-use, and their effect on maintaining habitat diversity, specific management interventions are recommended. In this way, relevant management actions (C1, C2 & C3) will be “climate proof” – that is, sustainable and effective under future climate change scenarios.

8.2.1 Management recommendations: wet meadows / shallows and reedbeds

Open areas should be available in the altitudinal range from 849 m to 851 m to make sure that wet meadows and open shallows are available under all projected water levels in the distant future. Annual clearance should follow seasonal water level fluctuations. It can best take place around October, when there is the seasonal lake lowstand, and reedbeds should be cleared up to 20 cm below lake-level; this strategy would make sure that shallows are available during the following spring/summer, irrespective of wet/dry conditions.

The clearance of shoreline plots should ideally be rotational, following seasonal water level fluctuations, to further the gradual rejuvenation and thinning-out of the reedbelt zone. Stimulating larger inter-annual water level fluctuations, between 848.50 m and 850.60 m, in combination with rotational clearance at seasonal lowstands, would mimic traditional use of the shoreline. Such integrated sluice and vegetation management would yield most benefits: shallow areas become available under all projected lake levels, nutrients / biomass around the lake are reduced, the potential spread of reedbed fires is diminished and the reedbed species-composition may diversify.

Furthermore, reedbeds in front of stream-mouths and in the Koula isthmus channel should be entirely removed. Thus the lateral spread of reedbed fires is prohibited. Shallows will be available along these corridors under all lake levels, and the access of fish to streams is facilitated.

Finally, new wet meadows may be created around alluvial shorelines of Greater Prespa Lake, for example along the isthmus and mouth of the Aghios Germanos River. These shallow areas would be characterized by different lake level and (lower) water temperature conditions. As such, they would complement the available shallows around Lesser Prespa Lake, and offer alternative/additional foraging- and fish-spawning areas. In the light of uncertainties associated with future projections, it is best to offer multiple mitigation strategies thus increasing the chances on a positive outcome.

8.2.2 Management recommendations: fire corridors

The location of corridors protecting reedbeds from fire should be integrated in the general reedbed vegetation management.

Vegetation in drainage ditches should be removed, as fires often spread from these sites.

Wet meadows double as fire-breaks. Their location should therefore also be chosen with this criterion in mind. Meadows that are connected to wet meadows are particularly effective fire-breaks. Between the area of bean cultivation and the reed beds should be a strip of (wet) meadow land; especially at the NW side of the lake, fires started on fields used for bean cultivation spread directly into the reedbelt as there is no buffer zone.

To prevent the lateral spread of fires, reedbeds in front of stream-mouths and in the Koula isthmus channel should be entirely removed. Near specific nesting sites, reedbeds may also be entirely removed in corridors perpendicular to the shore; such corridors should preferably be centered on deep water-filled depressions.

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