Food and Agriculture Organization of the United Nations

EIFAAC – International Symposium

Adaptation of inland fisheries and aquaculture to climate change

Stare Jablonki , Poland 3 – 6 September 2017

European Inland Fisheries and Aquaculture Advisory Commission

Effects of global climate change on fisheries in the Trasimeno Lake (central Italy), with special reference to the *Carassius auratus* invasion

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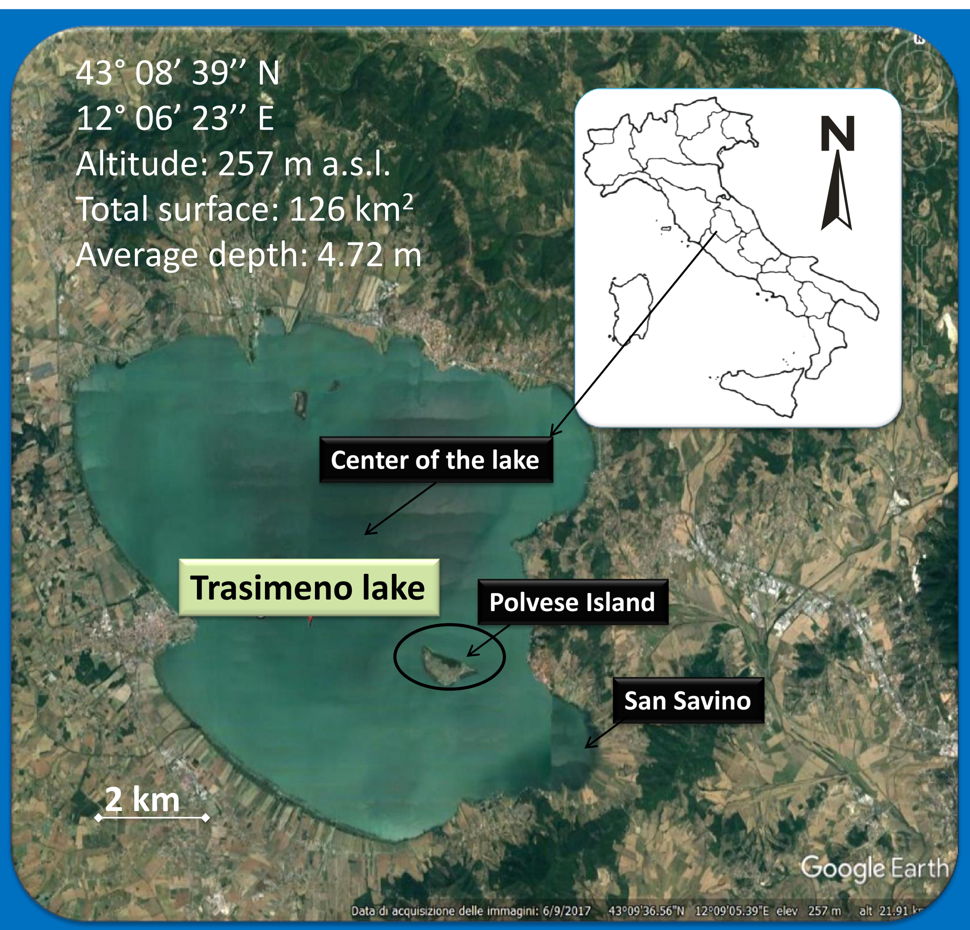

Fig. 1 – Location of environmental data collection sites

Introduction

The global climate changes have led to a gradual warming of the planet resulting in decreased rainfalls and rising temperatures in Mediterranean inland waters, with consequent negative ecological impacts on the functionality and on the biodiversity of lake ecosystems (Jeppesen et al., 2015). In the Trasimeno lake (Fig. 1), that is the largest laminar lake in Italy (124.3 km²), many exotic fish species have benefited from these changes as they are thermophilic and characterized by wider habitat preferences. Among these, the expansion of the goldfish *Carassius auratus* is particularly worrying due to the high invasiveness of the species that is currently dominant in the fish community of the lake. The aims of the research were to analyse the changes occurred over time in fisheries and in the fish populations of the lake in relation to environmental parameters, and to highlight the ecological impacts due to the alien goldfish invasion.

Materials and methods

Data on fish yield were collected by the professional fishermen of S. Feliciano cooperative during the years 1956-2014. Also data collected by electrofishing in the years 1993 and 2014 were used: electrofishing has been used in the littoral area of the lake in six sites. At each site, a variable number of transects of varying lengths were examined and the time of samplings measured (fishing effort). The CPUE (Catch Per Unit Effort) was defined as biomass per unit of time (g min^{-1}). Meteorological data were collected by the Hydrographic Service of the Umbria Region at two sampling sites located at Polvese Island and San Savino (Fig. 1). The chemical-physical data of water were collected by ARPA Umbria at a sampling site located in the center of the lake (Fig. 1). To verify the relationships among the environmental conditions, a PCA analysis was performed; the matrix used 6 environmental variables and 72 observations (monthly data x 6 years).

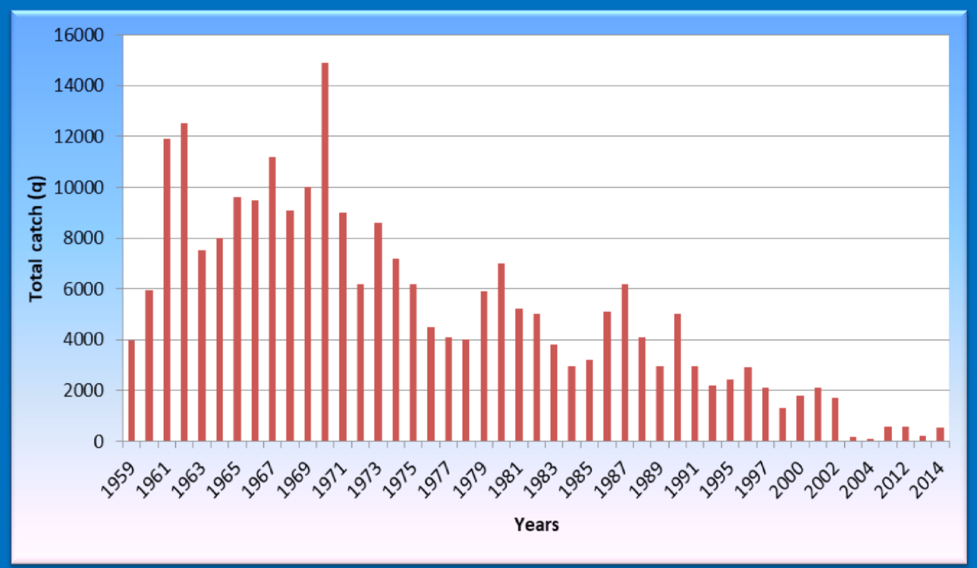

Fig. 2 – Total catch of professional fishermen (expressed as biomass) over the period 1959-2014

Results

Currently, the fish fauna of the Trasimeno lake includes 19 species (Tab. 1). The trend of the total catch over time showed a progressive decrease in term of biomass, more markedly in the last decades (Fig. 2). The comparison between the mean CPUEs in the years 1993 and 2014 confirmed the progressive decline in the abundance of the native population of *Esox cisalpinus* , while for *C. auratus* a significant increase in catches was detected in recent times (Fig.3); the analysis of the yeld shown a similar trend (Fig.4), despite goldfish was not a commercial species for professional fishermen.

The mean air temperature values (years 1988-2016) showed a clear increasing trend over time (Fig. 5) while, on the contrary, for the monthly mean rainfall (years 1951-2016) and the annual mean transparency (years 2002-2014) the plots highlighted the tendency for an overall decrease in time (Figg. 6-7). Hydrometric levels showed a fluctuating trend, with very marked drought periods (i. e. years 2003 and 2007), although in recent times the levels of the lake have increased (Fig. 8). The synthesis of the environmental parameters carried out by PCA analysis showed the positive relation of the goldfish abundance with water temperature and conductivity, while an inverse relation of the species with hydrometric levels and transparency was observed (Fig. 9). Contrary to what has been shown for goldfish, carp *Cyprinus carpio* Linnaeus, 1758 and tench *Tinca tinca* (Linnaeus, 1758), the pike showed a direct correlation with transparency and hydrometric levels.

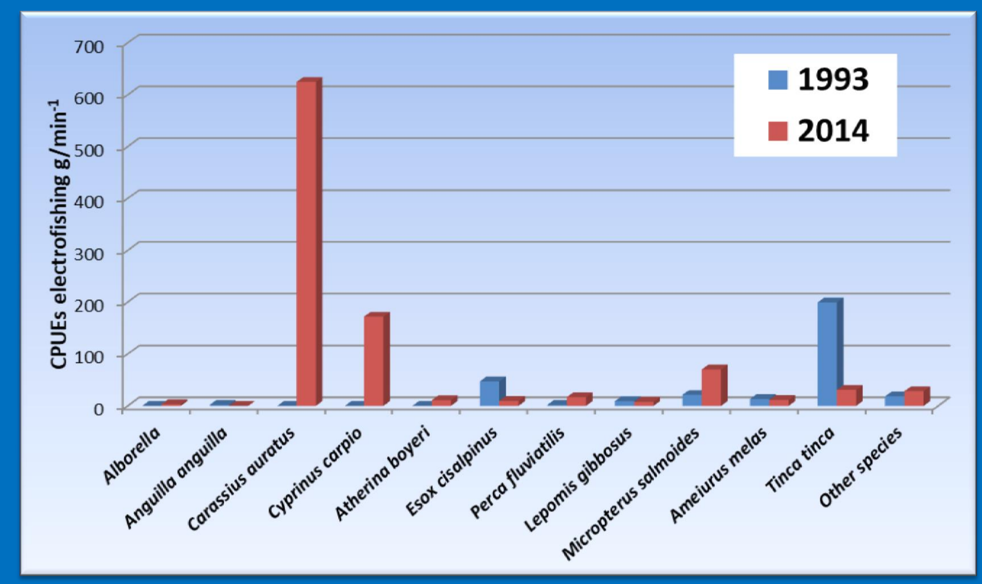

Fig. 3 – Annual average CPUEs for E. cisalpinus and C. auratus

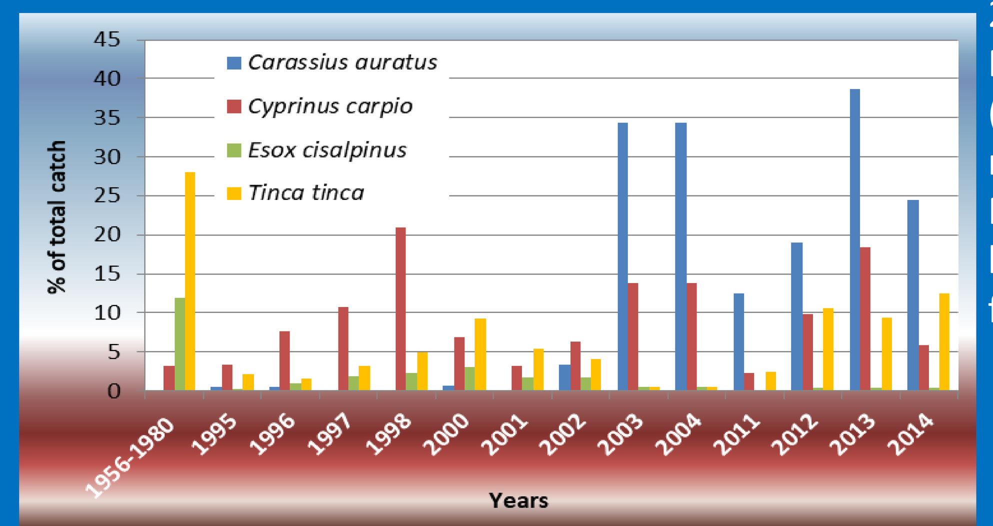

Fig. 4 – Percentage of the yield (expressed as biomass) for 4 fish species over the periods 1956-80, 1995-2004 and 2011-2014

Discussion

In the Trasimeno Lake increasing of water temperature and turbidity, combined with the occurrence of accentuated drought phases, have determined the progressive decrease of the total fish yield operate by local fishermen over time. Moreover, in the last decades marked changes in the fish community have occurred also due to the introduction of many alien species, most of which have been acclimated causing the decline in the number of native ones (Lorenzoni et al., 2002). In particular the demographic explosion of *C. auratus* in the lake, following its introduction occurred in 1988, had a strong impact on the fish community, especially on the endemic southern pike, and has seriously reduced the traditional fishing activities, highly correlated with the water levels. In fact, the southern pike have drastically declined in Lake Trasimeno due to reduced spawning areas, environmental degradation, interspecific competition for food with the exotic *Micropterus salmoides* (Lacepède, 1802) (Lorenzoni et al., 2002). Also *C. auratus* with own benthic feeding can contribute *to* threat *E. cisalpinus* reducing hydrophytic banks, increasing water turbidity, re-suspending nutrients and consequently supplying phytoplankton blooms (Lorenzoni et al., 2010; Carosi et al., 2017).

Moreover, climate change seems to favor exotic species such as the goldfish, since they are more tolerant to the water pollution (in terms of turbidity and salt content), resulted by the decreased hydrometric levels, as a consequence of the reduction in rainfall and of the increase in the evapo-transpiration of the lake observed in the last fifty years (Ludovisi & Gaino, 2010). Further analysis are certainly needed to confirm the hypothesis that the progressive decrease of the total catch over time could be related to the climate changes, but these first findings allow the assumption that the current scenario could worsen in the future due to the possible progressive decrease of the lake depth.

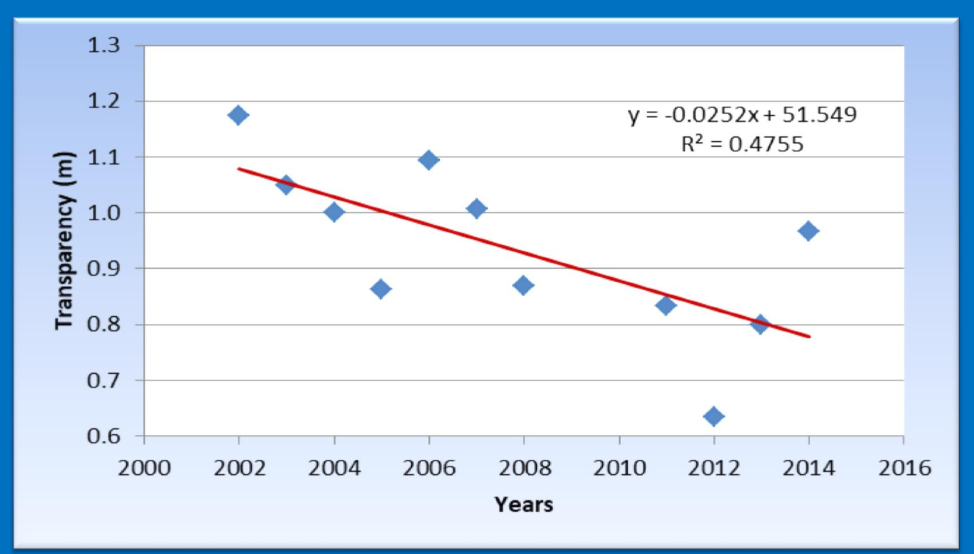

Fig. 7 – Annual mean transparency values from 2002 to 2014 (center of the lake)

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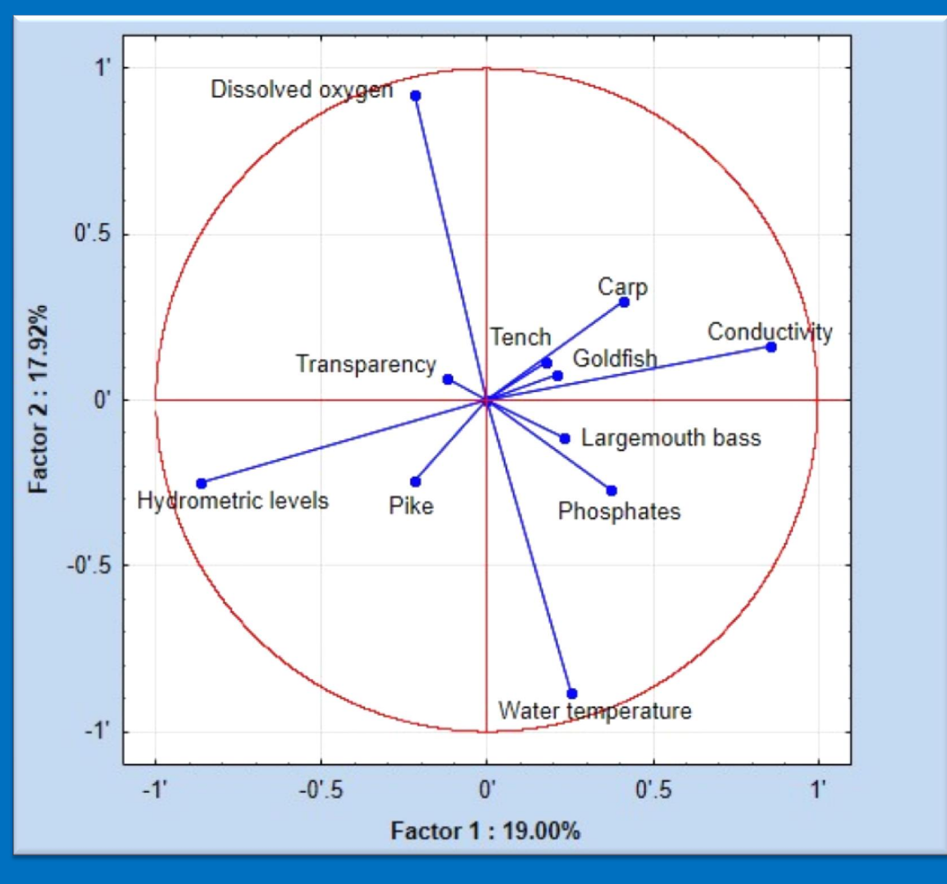

Fig. 9 – PCA results: plot of the variables projection on the factor-plane

Family	Species	Origin
Anguillidae	*Anguilla anguilla* (Linnaeus, 1758)	native
Atherinidae	*Atherina boyeri* Risso, 1810	non-native
Centrarchidae	*Lepomis gibbosus* (Linnaeus, 1758)	non-native
	Micropterus salmoides (Lacepède, 1802)	non-native
Cobitidae	*Cobitis bilineata* Canestrini, 1865	native
Cyprinidae	*Alburnus arborella* (Bonaparte, 1841)	non-native
	Carassius auratus (Linnaeus, 1758)	non-native
	Ctenopharyngodon idellus (Valenciennes, 1844)	non-native
	Cyprinus carpio Linnaeus, 1758	non-native
	Pseudorasbora parva (Schleger, 1842)	non-native
	Scardinius hesperidicus Bonaparte, 1845	non-native
	Squalius squalus (Bonaparte, 1937)	native
	Tinca tinca (Linnaeus, 1758)	native
Esocidae	*Esox cisalpinus* Bianco & Delmastro, 2011	native
Gobiidae	*Knipowitschia panizzae* (Verga, 1841)	non-native
	Pomatoschistus canestrini (Ninni, 1883)	non-native
Ictaluridae	*Ameiurus melas* (Rafinesque, 1820)	non-native
Percidae	*Perca fluviatilis* Linnaeus, 1758	non-native
Poeciliidae	*Gambusia holbrooki* Giraud, 1859	non-native

Tab. 1 – List of fish species occurring in Trasimeno lake and their origin

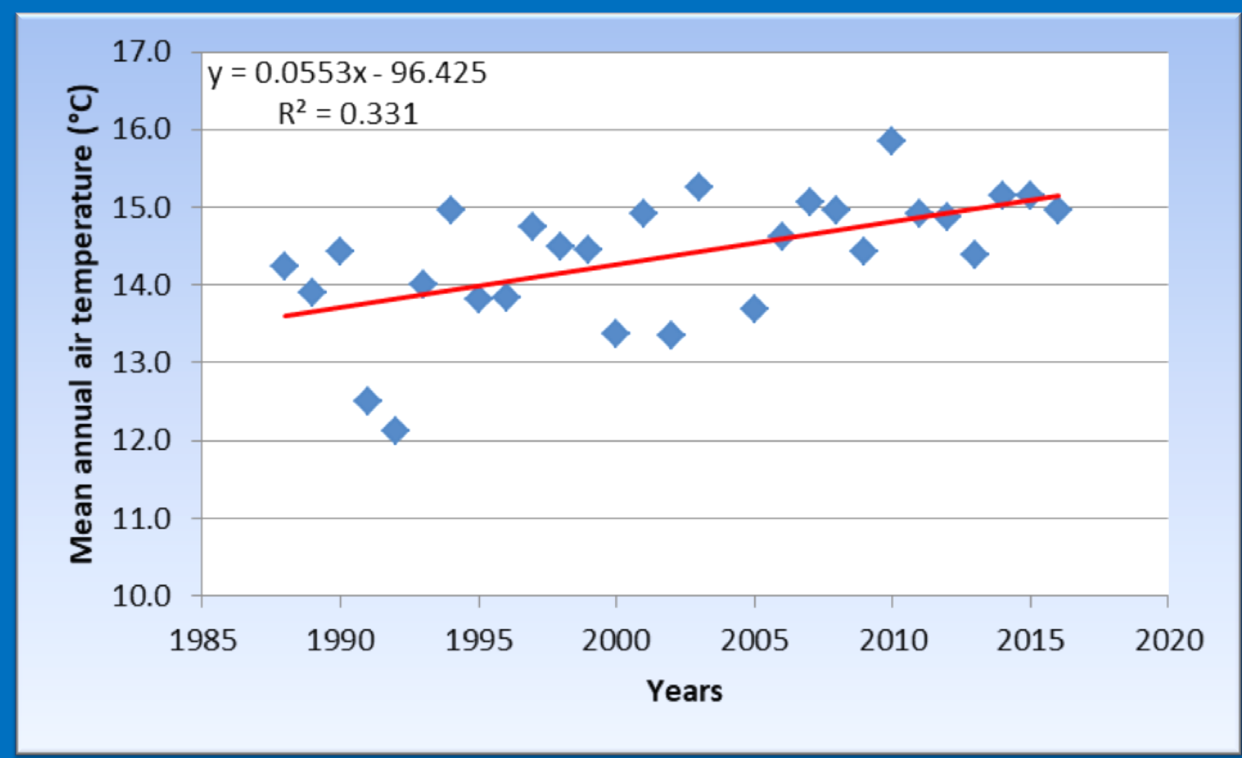

Fig. 5 – Trend of annual average air temperature from 1988 to 2016 (Polvese Island)

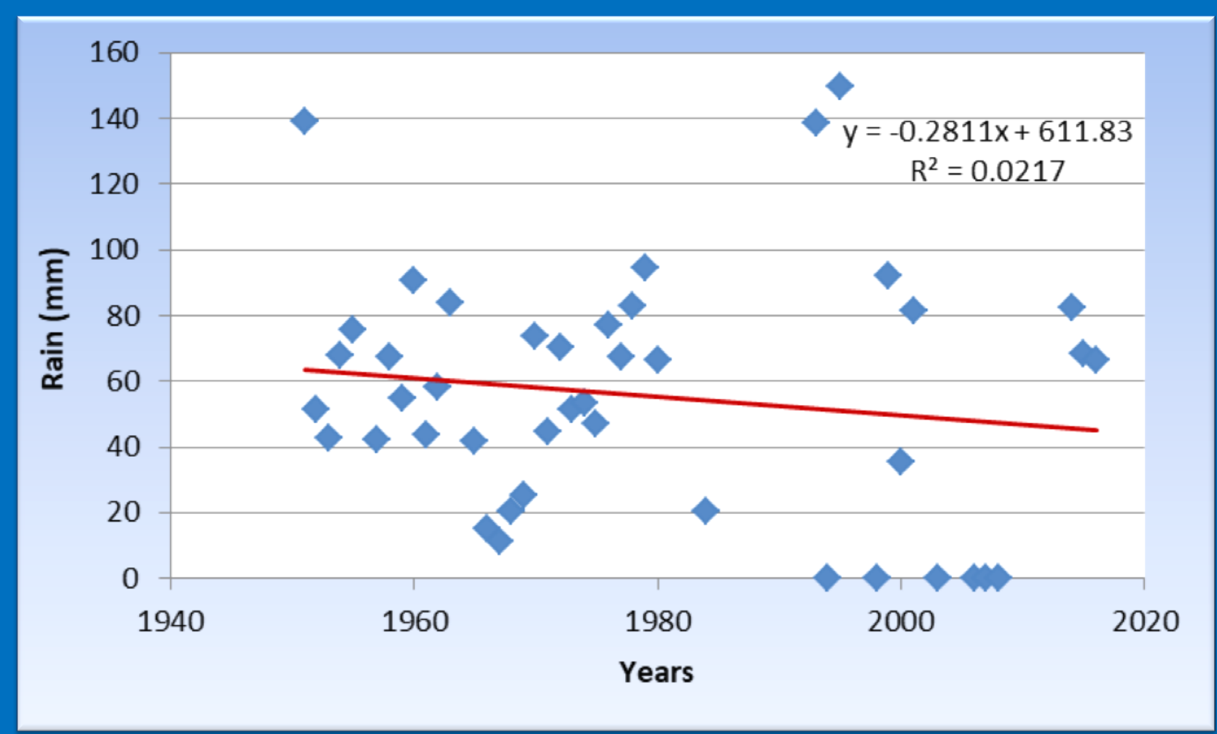

Fig. 6 – Monthly mean rainfall (Jan – Mar) from 1951 to 2016 (S. Savino hydrometer)

Fig. 8 – Annual mean hydrometric level from 1991 to 2016 (S. Savino hydrometer)