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Water level trends in the ponds of Siemianice Experimental Forest Farm

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Abstract

The results of a long-term water level monitoring in three forest ponds are presented in the paper. The ponds are located in the Wielisławice and Laski forest districts in South Wielkopolska, Poland. Two of the analysed ponds are natural ones supplied by precipitation and the third now is disused artificial fishpond of throughflow water management. Systematic water level measurements, as well as measurement of basic meteorological conditions – precipitation and air temperature – were carried out in the 2000–2016 hydrological period. The basic statistics as well as the trends in long-time changes in water levels, were determined using the nonparametric Mann–Kendall test were calculated. The results obtained were statistically inconclusive, but they indicated downward trends in water levels in the natural ponds and upward trends in water levels in the artificial pond. Although a statistically significant downward trend was observed in only one natural pond, it may suggest some negative changes occurring in the catchment of ponds in general.

Key words: *forest ponds, long-term monitoring, Mann–Kendall test, multiyear trend, water level*

INTRODUCTION

Ponds are defined as small man-made, or natural shallow bodies of water, which permanently or temporarily hold water [DE MEESTER *et al.* 2005]. However DE MEESTER *et al.* [2005] indicates possible wide size range of the ponds area of less than 1 m^2 to shallow lakes 1 km^2. The origin of ponds is very diverse, as they can be created by a wide range of natural processes (e.g. glaciation, land subsidence, river action and tree falls) and human activities (e.g. mineral extraction, water storage) [OERTLI *et al.* 2005]. The importance of ponds for the environment is multifaceted and incontestable. Small ponds could be very valuable elements of a landscape influencing the water regime of agriculturally managed areas [JUSZCZAK *et al.* 2007]. They play an important role in law level retention, supplying the neighbouring area with water during dry periods [KORYTOWSKI 2003; 2006; KOSTURKIEWICZ *et al.* 2004]. In some cases ponds can be the receivers of drainage water [FIEDLER 2011]. In the intensively farmed landscape of northern Germany, ponds strategically located to intercept water from drainage systems can significantly reduce the nutrient load of receiving waters through denitrification, sedimentation processes and uptake from wetland plants [CÉRÉGHINO *et al.* 2014]. As DOWNING [2010] notes, several analyses have shown the disproportionately great intensity of many processes in small aquatic ecosystems, indicating that they play an unexpectedly major role in global cycles. They are also a significant component of biodiversity [CÉRÉGHINO *et al.* 2007; 2014; HINDEN *et al.* 2005; NICOLET 2010; OERTLI *et al.* 2002]. Ponds are a resource of water for some rare flora and fauna species [NICOLET 2010]. Long-term changes of their condition can be an indicator of health of water resources of the neighboring areas as well as having a significant role in the Earth's carbon balance and climate change [MIRACLE *et al.* 2010]. Ponds and small lakes sequester carbon at rates that are orders of magnitude greater than virtually all other global ecosystems [DOWNING 2010]. Some ponds can also be viewed as persuasive model systems in ecology, evolutionary biology, and conservation biology [CURADO *et al.* 2011; DE MEESTER *et al.* 2005]. As has been pointed out, an important issue is the capacity for ponds and pond communities to respond to disturbance and to global change (early-warning systems) [CÉRÉGHINO *et al.* 2008]. This implies that near-pristine systems, such as naturally occurring ponds, should be identified as references in the investigated areas, and that long-term monitoring is necessary to assess temporal responses of ponds to local practices and/or global changes. Climate change is reported to dramatically influence the spatial and temporal distribution of air temperature and precipitation in the atmosphere [CHOJNICKI *et al.* 2010]. These changes observed in the last decades can lead to deterioration of water resources [GRAJEWSKI *et al.* 2013; KĘDZIORA *et al.* 2014; MILER *et al.* 2013] and thus threaten the existence of ponds, including forest ponds. In this study multiyear, standard observation of water levels in three forest ponds was used in order to analyze trends and map changes. The hypotheses are that there are significant trends of water level changes and that natural and artificial throughflow ponds will differ in water level statistics and trends.

MATERIALS AND STATISTICAL ANALYSIS

The research included systematic measurement of water levels in ponds taken with water level gauges. The measurement was carried out systematically once a week. The data were taken from the 2000–2016 hydrological period in the case of ponds No. 1 and 6 and 2000–2015 in the case of pond No. 5.

The basic statistics including minimum, maximum, median and quartiles 1 and 3 of water levels of each pond were calculated. The statistics were calculated separately in winter and summer half-years. The hydrological winter half-year in Polish conditions is between 1 November and 30 April and the summer half year is between 1 May and 31 October. The trend line was plotted and the line gradient was calculated. In addition, the non-parametric statistical Mann–Kendall test was used to analyse the changes in average water level trends in the ponds separately for winter and summer half-years. The trends in the changes in precipitation and air temperature were also determined. The Mann–Kendall test is defined as [BANASIK, HEJDUK 2012; GILBERT 1987; HIRSCH *et al.* 1982]:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \tag{1}$$

Where:

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} 1 \text{ if } (x_j - x_k) > 0 \\ 0 \text{ if } (x_j - x_k) = 0 \\ -1 \text{ if } (x_j - x_k) < 0 \end{cases} \tag{2}$$

$x_1, x_2, \ldots, x_n$ = data points.

If the value of S is close to zero it supports the no-trend hypothesis. An S value significantly higher than zero indicates an upward trend, while a S value significantly lower than zero suggests a downward trend. The tests were performed separately for the average water levels in winter and summer hydrological half-years, to allow for seasonal changes.

When $Z_S > Z_{kr}$, the trend is statistically significant; $Z_{kr} = 1.95$ when the confidence level is $\alpha = 0.05$. The value of Z_S is calculated from the following formula:

$$Z = \frac{S-1}{\sqrt{\operatorname{Var}(S)}} \text{ when } S > 0$$

and (3)

$$Z = \frac{S+1}{\sqrt{\operatorname{Var}(S)}} \text{ when } S < 0$$

For the time series n > 10, the variation is calculated from the following formula:

$$\operatorname{Var}(S) = \frac{1}{18} n(n-1)(2n+5) \tag{4}$$

STUDY AREA

The study was carried out in three small forest ponds located in forest districts belonging to the Siemianice Experimental Forest Farm (EFF). According to the regional geography of Poland [KONDRACKI 2011] the forests are situated on the Wieruszowska Plateau. This area is a region of South Wielkopolska and constitutes its southern frontier (Fig. 1). The ponds are located in the Wielisławice forest district (51°16'35.1"N 18°06'45.9"E – pond No. 1), and Laski forest district (51°13'14.3"N 18°03'03.5"E – pond No. 5 and 51°13'22.6"N 18°01'01.6"E – pond No. 6).

The total area of pond No. 6 catchment is about 37 ha. It is located in a forest catchment area (40%), which is dominated by fresh habitats. The catchment area is of which 60% are arable land. In the catchment area, 75% occupy browned fawn soils, and the dominant is clay sand that relies on silty-clay formations.

In the forest catchment area (7.5 ha) of pond No. 1, fresh habitats dominate. Soils predominate by soils with white rust (63%) grains of weakly clay sand. In the bottom there is an organic silt of flesh of 40 cm, and in layers located deeper and in the slopes, sands predominate.

Pond No. 5 is also located in a forest catchment area, with an area of about 20 ha, where fresh habitats predominate. In the immediate area to the pond there are moist habitats. Largest catchment area occupy sandy brown soils sour typical (45%). In 2006 the clearcutting was made at the nearest area.

In terms of hydrography, the site is part of the Pomianka River catchment area, which is a left-bank tributary of the Prosna River. The Marianka Siemiańska forest district is located in the north-east part of the Oleśnicka Plain mesoregion, Silesia nature woodland country, according to the 2010 nature-forestry regionalization [ZIELONY, KLICZKOWSKA 2012].

The data pertaining to forest type at particular sites were taken from the soil-forest site maps contained in the Soil-Habitat Assessment of Siemianice EFF (Pol. Zakład Usług Ekologicznych i Urządzeniowo-Leśnych) [ZUEiUL 1999]. The ponds' surface areas were measured in 1999 and ranged from about 0.097 ha (pond No. 5) to 0.35 ha (pond No. 6), and the average depth from about 1.0 m to 1.4 m.

Ponds No. 1 and No. 5 had similar capacity, 1300 m^3 and 1164 m^3 respectively, while pond No. 6 is the biggest one, with average capacity of about 4900 m^3 (Tab. 1). Ponds No. 1 and No. 6 are natural ponds, the sole water origin being precipitation.

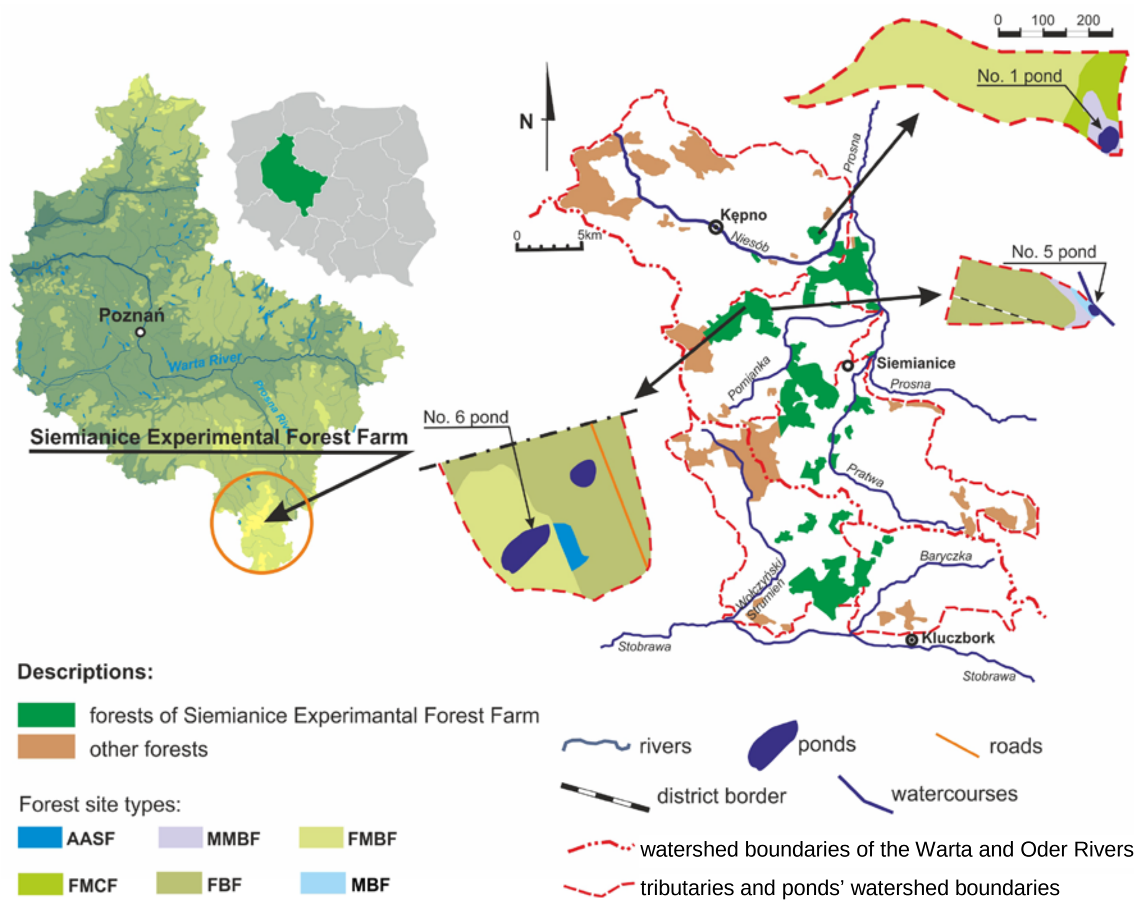

Fig. 1. Location of Siemianice Experimental Forest Farm as well as ponds' catchment forest habitat maps; descriptions of forest site types: AASF = ash-alder swamp forest, MMBF = moist mixed broadleaved forest, FMBF = fresh mixed broadleaved forest, FMCF = fresh mixed coniferous forest, FBF = fresh broadleaved forest; MBF = moist broadleaved forest; source: own elaboration

Table 1. Basic characteristics of analysed ponds (July 1999)

Pond number	Type of pond	Pond's surface area (ha)	Average depth (m)	Average capacity (m^3)	Pond's length (m)	Pond's width (m)
1	natural	0.13	1.0	1 300	40	35
6	natural	0.35	1.4	4 900	115	30
5	artificial, throughflow	0.097	1.2	1 164	48	20

Source: own study.

Pond No. 5 is artificial, with a subsurface spring providing water and with a ditch forming an outflow (Fig. 2). It is an old fishpond which is no longer in use.

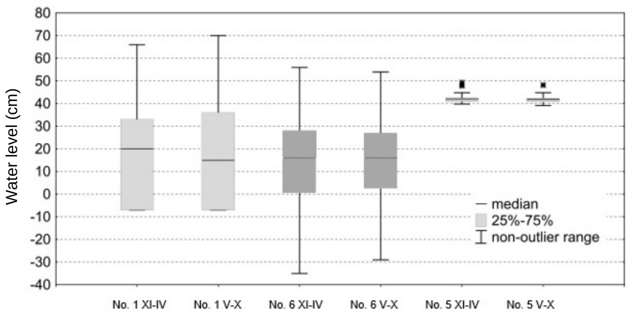

Fig. 2. Basic statistics of water levels in analysed ponds No. 1, No. 6, and No. 5 separately for winter (XI–IV) and summer (V–X) half-years in analysed long-time (0 value is equal "0" level on gauge – negative values were measured below "0"); source: own study

RESULTS AND DISCUSSION

The Wielkopolska lowland region is one of the driest Polish regions in terms of precipitation. The perennial (1975–2000) average yearly precipitation at Siemianice meteorological station is about 567 mm (206 mm in winter and 361 mm in summer half-year). The multiannual average temperature is about 2.5°C for the winter half-year and 15.4°C in the summer half-year (yearly average 8.9°C). Average half-year air temperatures and precipitation in the period of 2000–2016 hydrological years indicate changeability of weather conditions (Tab. 2). The deviations were from –57 mm up to +165 mm from the multiannual precipitation average in winter half years. A further deviation from –179 mm to +202 mm in summer half-year was also observed. The deviations of winter half-year average air temperature were from –2.5°C to +2.0°C and –1.0°C and +1.2°C in summer half-years. Very cold and very warm as well as very dry and extremely moist half-years were observed. The negligible *S* values of Mann–Kendal statistical

Table 2. Average temperatures (*T*), precipitation (*P*) and their deviations from multiannual average (1975–2000) as well as *S* value for winter and summer hydrological half-years in the analysed period 2000–2016

Hydrological year	Winter half-year (November–April)				Summer half-year (May–October)			
	T (°C)		*P* (mm)		*T* (°C)		*P* (mm)	
	average	deviation	sum	deviation	average	deviation	sum	deviation
2000	+4.2	+1.7	239	+34	+16.6	+1.2	405	+44
2001	+4.1	+1.7	227	+21	+16.3	+0.9	462	+101
2002	+2.1	–0.3	213	+7	+15.6	+0.1	325	–36
2003	+0.1	–2.3	150	–57	+15.4	+0.0	371	+10
2004	+3.2	+0.8	273	+66	+15.0	–0.4	253	–108
2005	+0.9	–1.5	223	+16	+16.3	+0.9	237	–124
2006	+0.2	–2.3	371	+165	+16.4	+1.0	262	–99
2007	+2.4	–0.1	252	+45	+15.1	–0.3	301	–60
2008	+2.7	+0.2	252	+46	+15.4	+0.0	244	–117
2009	+1.2	–1.3	184	–22	+14.8	–0.6	441	+80
2010	+0.5	–1.9	243	+37	+14.4	–1.0	563	+202
2011	+2.2	–0.3	229	+22	+16.2	+0.8	270	–91
2012	+1.9	–0.5	175	–31	+15.7	+0.3	427	66
2013	+0.0	–2.5	258	+52	+15.5	+0.1	453	+92
2014	+4.5	+2.0	169	–37	+16.1	+0.7	368	+7
2015	+3.5	+1.0	156	–51	+16.4	+1.0	182	–179
2016	+3.8	+1.4	256	+50	+16.3	+0.9	357	–4
S	–12		–6		0		–4	

Source: own study.

calculation for winter and summer half-years for air temperature and precipitation suggest no trend in its changes in any given analysed long-time. However, a period of 17 years period cannot be considered as long in terms of climate condition changes.

Basic statistics of water level differ significantly in individual ponds. In pond No. 1 *Q*1 quantile (25%) equals minimum values. It suggests asymmetric distribution of water level which means that this pond used to be dry periodically both in winter and summer half-years.

A typical box plot for pond No. 6 suggests normal distribution of the water levels in this pond. However the box plot for water level in throughflow pond No. 5 differs both from No. 1 and No. 6 natural ponds. The range of minimum and maximum levels in pond No. 5 is about 10 cm, while in No. 1 and No. 6, it is about 75 cm and 100 cm, respectively. It is the result of throughflow type of water management in the pond No. 5 and water management ruled mainly by precipitation-evaporation processes in natural ponds No. 1 and No. 6.

The negative *S* values as well as negative linear trend gradients indicate a decrease in average water level in pond No. 1 and No. 6 in winter half-years for the 2000–2016 period (Fig. 3).

However this decrease is not confirmed by statistical significance of *S* values – the values are *S* = –46 and *S* = –48 respectively and are barely lower than 49, which is a threshold for α = 0.05 significance level. The lack of statistically significance in case of *S* values in average water levels in winter half-year may be caused mainly by the high average water level in 2014. Such levels observed in all of the ponds were the effects of the very moist 2013 hydrological year (Tab. 2). In contrast to the trends observed in ponds No. 1 and 6 the multi-yearly trend of water level changes in pond 5 suggest a slight increase in water level. However, *S* values for winter half-years are statistically insignificant. It is also worth noting that yearly half-year average water levels do not differ much in each year in the period from 2000 to 2007, which confirms basic statistics for this pond. However, from 2008 to 2015 greater differences between average water levels were observed. These could have been caused by the clear-cutting in the nearest surroundings of the pond's carried out in 2006.

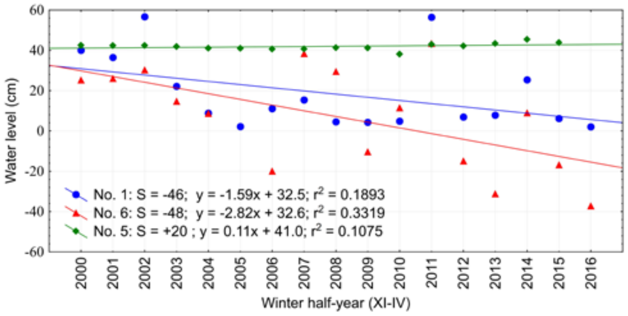

Fig. 3. Average winter half-year water levels in ponds No. 1, No. 6 and No. 5, *S* values and linear trends for 2000–2016 hydrological years; source: own study

Similar results of water level trends for the summer half-years in the analysed period were observed. In the case of ponds No. 1 and No. 6, negative linear trend gradients of water levels suggested downward trends (Fig. 4). It is also confirmed by negative *S* values (*S* = –24 and –49 respectively). However, *S* = –49 in the summer half-years for pond No. 6 is statistically significant. A slightly increasing water level trend in pond No. 5 was observed in summer half-years, as was also seen in winter half-years.

The results for ponds No. 6 and No. 5 suggest a process of pond decline. In the analyzed area a decrease of groundwater levels and soil moisture in forest habitats was also observed [STASIK *et al.* 2016; STASIK, KĘSICKA 2017]. The causes of this process are inconclusive, especially as it

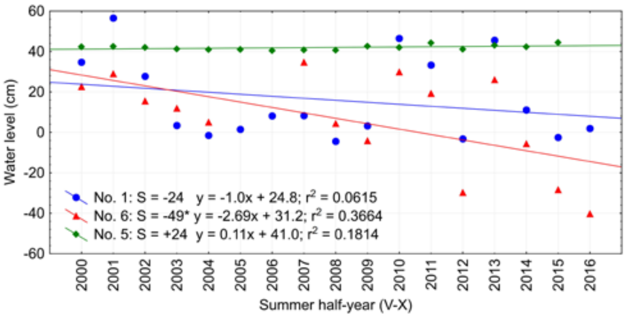

Fig. 4. Average summer half-year water levels in ponds No. 1, 6 and 5, *S* values (*statistically significant) and linear trends for 2000–2016 hydrological years; source: own study

is uncertain whether the process is persistent or temporary. Such a process in some parts of Poland has been observed by several authors, but the reasons for pond disappearance can differ. In long-term research Pieńkowski *et al*. [2010] concluded that there had been a decline of over 1200 ponds on the undulating moraine plateau of Wełtyńska Plateau as well as the outwash plain of Gorzowska Plateau and Myśliborskie Lakeland. The decline of ponds on the outwash plain was caused by altitude differences, whereas no conclusive reason for pond disappearance on the moraine plateau was established. Kramkowski *et al*. [2016] in a long-term analysis over 200 years based on the maps of the Głusza swamp in the Krajeńskie Lake District, observed changes in humidity, causing the number of ponds to disappear and transformation into wetlands, in the early 21st century. They observed a threefold decrease in the share of water space between 1996 and 2010, resulting in an increase in foresting. According to the authors, this could have resulted from the influence of drainage devices which were installed in the 1980s. Major [2013] indicated disappearance of water in 9 out of the 15 observed ponds in the Upper Parsęta catchment (West Pomerania) as the result of drought only in one hydrological year, 2006. It is worth noting that the small area of the pond and its catchment make it sensitive to yearly changes in meteorological condition, and pond water resources can be restored in a wet hydrological year. Juszczak and Kędziora [2003] based on analyses of the maps of the Wyskoć catchment agricultural area in south-western Wielkopolska established that 25 water reservoirs were entirely full from 1983 to 1996. Simultaneously, 65 artificial reservoirs were dug and a further 21 were rebuilt and enlarged.

Research carried out in northern France indicated a sharp reduction in the number of ponds in an agricultural-urban area that underwent a major land use change over three decades [Curado *et al*. 2011]. Also in England a decrease of pond number was observed in the 20th century [Wood *et al*. 2003] as the result of increasing pressure due to agricultural land drainage, pollution and urban development. On the other hand, an increase of pond number in Britain in the 1998–2007 period was observed [Williams *et al*. 2010]. A climate-driven decrease in the size and number of tundra ponds was observed by Andresen and Lougheed [2015] in drained thaw lake basins in the Alaskan Arctic Outer Coastal Plain. Thus, the decline of ponds can be caused by many factors. According to the pond manifesto [EPCN 2007] published by the European Pond Conservation Network (EPCN), the widespread loss and degradation of ponds throughout Europe is continuing, with impacts on freshwater biodiversity resources and the integrity of ecological networks.

Climate changes also have major effects on fluctuations water level. Parsons *et al*. [2004] found from research that more than 50% of wetland water loss during the summer months was caused by the flow of groundwater caused by coastal vegetation uptake, while the remainder was due to evapotranspiration in the pond area. When hydrological processes and their response to land use in the catchment area and climate are known, it is easier to simulate the water level in a given lake or pond by means of a water balance equation [Su *et al*. 2000]. It happens that in many cases hydrological processes are poorly understood, which causes a lot of uncertainty in model forecasts.

CONCLUSIONS

1. The results of Mann–Kendall test calculation indicate no trend in air temperature nor precipitation in winter and summer half-years in the period 2000–2016. Moreover, the analyses of meteorological conditions confirmed their variability, which is a characteristic feature of the climate of the Wielkopolska Region, Poland.
2. Water level characteristics in throughflow pond No. 5 differ both from natural ponds No. 1 and No. 6 in terms of the range of minimum and maximum levels. It is the result of throughflow type of water management in pond No. 5 and water management governed mainly by precipitation-evaporation processes in natural ponds No. 1 and No. 6.
3. Negative values of *S* indicate slightly downward trends in average water levels in natural ponds No. 1 and No. 6, both in winter and summer half-years in the analysed multiyear period 2000–2016. However, only in the summer half-years in pond No. 6 was the *S* value statistically significant. Thus the obtained results are inconclusive.
4. A statistically insignificant, slightly upward trend in water levels was observed in winter and summer half-years in the case of pond No. 5. The water levels were the most balanced in this pond, which is the effect of a constant supply of spring water.

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