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Trends in occurrence of thermophilous dragonfly species in North Rhine-Westphalia (NRW)

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Abstract
Since 1996 the "Workgroup Odonata in North Rhine-Westphalia" ("AK Libellen NRW") has built up a data base including about 150.000 data sets concerning the occurrence of dragonflies in North Rhine-Westphalia (NRW). This data confirms an increase and spread of some thermophilous dragonfly species in NRW, and the effects of climate change evidenced by an increasing average temperature, are considered to be important reasons for this process.

Keywords
dragonflies, climatic changes, North Rhine-Westfalia, monitoring, "Mediterranean species"

The area

Covering 34.100 km^2 North Rhine-Westphalia (NRW) is one of the biggest federal states of Germany with the largest number of inhabitants (about 17 million people). The Rhine-Ruhr-area in the center of NRW is the largest and most densely populated area in Europe.

The country is mainly flat (65 % of its area is situated between 10 and 150 m a.s.l.). The southern parts are occupied by mountainous areas with altitudes up to

840 m a.s.l. The lowland is a mainly open landscape dominated by highly developed agriculture with several urban and industrial centers. The mountains are dominated by woodlands, nowadays the majority consisting of spruce forests (LÖBF 2005).

The climate

North Rhine-Westphalia is situated in a transition area of the atlantic and continental climate. The predominating western winds carry mainly wet air from the atlantic low pressure areas. Therefore NRW has a warm-moderate rain climate with mild winters and relatively cool summers (DWD 1989). Corresponding to the orography NRW is also climatically divided into lowlands and mountainous areas. The annual average temperature equates to more than 9°C in the lowlands and 5°C in the mountains respectively. As a region of even higher temperatures the conurbation in the Rhine-Ruhr-area is in an exceptional position.

The temporal distribution of precipitation has a summerly maximum in the lowlands and an additional winterly one in the mountainous countries. Effects of luff and lee in the mountains produce differences in the amounts of precipitation and intensify the differences of regional climates. So the precipitation remains below 750 mm in major parts of the Northwestern region "Niederrheinische Bucht" whereas it reaches more than 1.100 mm in the mountainous regions. Therefore NRW has a high diversity of regional climatic differences which for example also cause large amplitudes in the vegetation periods.

The inventory of waterbodies and its historical development

North Rhine-Westphalia is a country with abounding water. It is strongly marked by a dense net of river systems including the main rivers Rhine, Ems and Weser which contribute to the North Sea. Nevertheless especially in the lowlands only a few semi-natural rivers and brooks are left, the most running waters being regulated and paved.

The quality of water instead is much better today than it used to be some years ago, especially in the age of industrialization about a hundred years ago when this had been much worse. Also a growing number of projects restoring parts of rivers and brooks to its former natural conditions indicate a positive development of the running water bodies.

Natural lakes do not exist in NRW. The only particular exception is the "Heiliges Meer" in the North of the country. This area consists of a group of small lakes, resulting from erosion and the caving in of salty layers in the underground. The lakes are only some hundred years old, several are even younger. But since a hundred years ago a lot of artificial lakes have been constructed as reservoirs or gravel pits all over the country. They are mainly concentrated in the southern mountainous country called "Sauerland" and within the alluvial floodplains of the rivers Rhine and Weser.

The mountainous areas are rich of springs and brooks. Here small water bodies exist e.g. man-made mill ponds or barrages. Until the 18th century a lot of swamps and bogs had existed in the lowlands, but only small rests have remained until today. The ground water level has decreased nearly everywhere and the diversity and density of small water bodies of the historical landscape does not exist any more. Although construction of new ponds and wetland areas is often practiced, these water bodies are subject to an accelerated succession due to eutrophication (in a high amount caused by air pollution) and also influenced by higher temperatures.

The "Workgroup Odonata North Rhine-Westphalia" (AK Libellen NRW)

In 1996 this honorary working group was founded to work on the protection and investigation of Odonata in NRW. The AK organizes annual meetings for all collaborators giving new information and exchanging experiences with the participants. Circular letters and mailings also offer recent information to every member. In every summer a weekend-meeting is organized to investigate dragonflies and collect data in areas which have not been well-investigated yet.

Active collaborators can choose between two ways of ascertaining data: first by observing only a few selected water bodies intensively and continuously to get a close image of the entire inventory of dragonflies autochthonous in these water bodies. They have to undertake several excursions (at least 5) in a year for 2–4 years in a row. The second way is trying to cover a larger area and observing numerous water bodies but undertaking only a small number of excursions (1–3) to each of them. Despite of this all data is welcome.

Information is also available from our homepage (www.ak-libellen-nrw.de) containing dates of meetings, recent news of interesting dragonfly-records, a download of the recording manual, the current red list, a bibliography as well as distribution maps of all known dragonfly species in NRW.

The AK organizes training courses on exuviae and adult dragonflies. It supports dissertations and other works on dragonflies. There is also an exhibition available to be rent for presentations in order to give information on dragonflies to a great public.

The AK is part of an efficient network together with the LANUV (the major governmental institution for ecology and nature conservation in NRW), the "Biologische Stationen" (institutions for nature conservation on the level of districts), the "GdO" ("Gesellschaft deutschsprachiger Odonatologen") and other fieldworking groups (e.g. the "Work Group on amphibians and reptiles", "AK Herpetofauna NRW").

Aim of this work is a publication about the dragonflies in NRW and the cooperation with other dragonfly-protection-groups all over the world.

Due to this intensive work on dragonflies in the last years interesting new knowledge could be attained but also new questions arose. One obvious result is the observation of positive trends in occurrence of several thermophilous species and other observations (such as a change in the phenology of some species) which indicate a warmer climate in NRW.

The climate change

The known global effects of the climate change are also visible in NRW. A report of regional climate scenarios for NRW (Gerstengarbe et al. 2004) shows the following results:

"Between 1951 and 2000 significant climatic changes could be observed in NRW. The most important changes are:

– an increase of temperature in the annual average up to 1,5 K
– a decrease of days with frost in average up to 20 days per year
– an increase of summer days (meteorologically: days with more than 25°C) in average up to 20 days per year
– an increase of precipitation in the annual average of more than 100 mm in some areas
– an increase of days with strong precipitation up to 8 days a year and a highly significant decrease of days (up to 40) with no or only small precipitation".

In respect to the climatic change in the near future (2001–2055) the report points to the following trends based on statistically solid proved probabilities:

"The temperature will increase for at least 2 K and therefore the number of meteorologically "cold days" (with frost) will decrease whereas the number of "summer days" will increase.

The precipitation will increase on a lower level.

The increase of water steam pressure will be overcompensated for the reason of increasing temperature and therefore the relative atmospheric humidity will decrease.

In connection with a clear increase of the air pressure the time of sunshine and global radiation will raise as well as the clouding will decrease slightly."

The database

Due to the almost complete interpretation of publications on dragonflies in NRW and other sources like unpublished reports, collections and the current data from the AK-observations a solid database with now about 150.000 data sets has been established. The spatial and temporal distribution of the acquired data is shown in the figures 1a and 1b. It reflects a nearly complete coverage of NRW and a very strong increase of data based on the intensive and systematical work of the AK in the last decade. The peaks before 1996 represent data from publications on dragonflies which summarize the knowledge about the species for certain periods of time (for example Le Roi 1915 or Kikillus and Weitzel 1981).

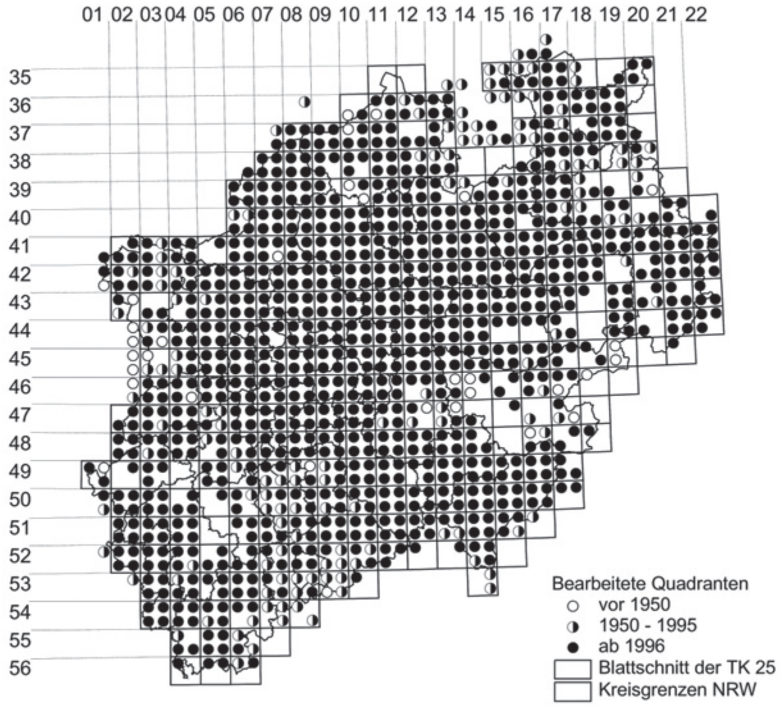

Figure 1a. The distribution of data on dragonflies registered in the data base of the AK Libellen NRW on the base of large scale map (1:25.000) (m) –quadrants, differentiated for three time periods (before 1950, 1950–1995, since 1996); one grid cell represents an area of about 5,5 × 5,5 km.

Nevertheless the fact of an increasing amount of data collected in the last decade has to be considered for the interpretation of any results. It is not always possible to determine whether the "increasing" of a dragonfly species results from climatic effects, other factors (f.e. offer of habitats or changing of habitats for example due to eutrophication) or only because of intensified observations.

The expansion of thermophilous dragonflies

Methods

The trends in occurrence of Odonata species in North Rhine-Westphalia were analyzed on the basis of the number of observations for each year and species. A data record corresponds to the observation of a species in an investigated area for each day, independent from number or autochthonousness of the species. To take into account the different intensity of this observation (the development of the number of observations is shown in fig. 1b) this number was set in relationship with the total number of

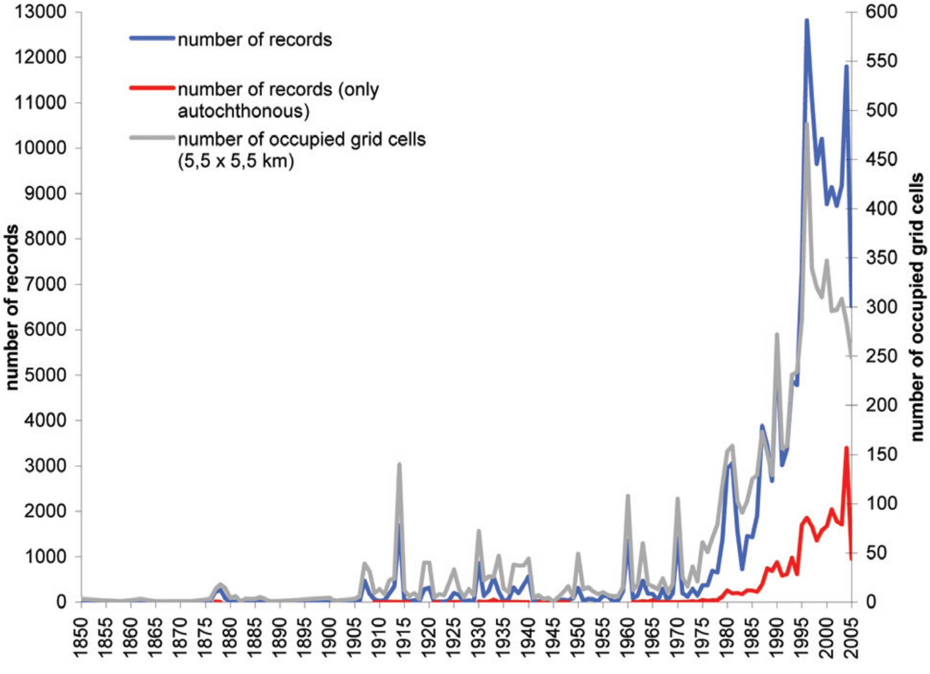

Figure 1b. Development of dragonfly observations for NRW in the last 155 years, differentiated for observations (blue), observations with proved autochthony (red) and coverage of quadrants of the large scale map "1:25.000" (m) (grey).

observations per year. So for each species the respective proportion was computed and its relative frequency was determined. With these annual portions an inventory trend analysis on the basis of the Spearman rank-order correlation coefficient (Spearman's rho) with the statistical program SPSS 11.5 was computed. The classification of areal types ("Faunenelemente") corresponds with St. Quentin (1960), Sternberg (1998) and Sternberg and Buchwald (1999, 2000).

Results

The results of trend analyses are given for some thermophilous species in table 1. In addition the below table (Table 1) refers to publications for their first records ("year") in NRW and current new works on their occurrence in our country.

Table 1 shows the currently known first records of some thermophilous species in NRW and its origins. It elucidates that apart from a few species (*Coenagrion scitulum*, *Crocothemis erythraea*, *Anax parthenope*) single observations of most of them have already been made in NRW since the 19th century. This indicates the dynamic distribution patterns of a very mobile dragonfly species and the influence that already a few years with favourable weather conditions could have.

Table 1. Year and referred publication of first records of thermophilous species in NRW and important new publications for the occurrence of the species, the Spearman rank-order correlation coefficient (Spearman's rho) and its level of significance for the trends of occurring for two regarded periods.

Species	Year of first record	Origin (reference)	Important new references	1850 – 2005		1980 – 2005	
Aeshna affinis	1913	KRIEGE (1914)	Bauhus (1996)	0,60		**0,56**	**
Anax parthenope	1983	Lempert (1984)	Böhm (2003)	**0,85**	**	**0,42**	*
Coenagrion mercuriale	1883	KOLBE (1886)	Conze & Göcking (2001), Müller (2003), Röhr (2006)	0,12		**0,54**	**
Coenagrion scitulum	1961	KIEBITZ (1962)	Grebe, Hofland & Rodenkirchen (2006)	0,25		**0,43**	*
Crocothemis erythraea	1977	FERWER (1989)	Bauhus (1996), Böhm (2003), Schmidt (2004)	**0,86**	**	**0,82**	***
Erythromma viridulum	1877	KOLBE (1878)	-	0,57		**0,58**	**
Lestes barbarus	1872	KOLBE (1878)	Schmidt (2004)	-0,37		0,38	
Orthetrum brunneum	1888	LE ROI (1915)	Krüner (2001)	0,16		**0,42**	*
Sympetrum fonscolombii	1872	KOLBE (1877)	Kordges & Keil (2000)	0,06		0,37	
Sympetrum meridionale	1930	KRABS (1932)	Böhm (2002)	0,23		**0,50**	**

Level of significance. **extra bold:** significant correlation (P<0,05)

* 0,01<P<0,05

** 0,001<P<0,01

*** P<0,001

But it also proves significantly the increase of thermophilous dragonfly species in North Rhine-Westphalia. Especially in the last 25 years the positive trend is at least significant for eight out of ten species. This development obviously is connected with the increase of average temperature in the same period of time. Furthermore the rapidity and intensity of the outspread of some species has been advanced by the change of habitat availability. Those developments have been observed f. e. for *Crocothemis erythraea* and *Erythromma viridulum* in the alluvial floodplains of the rivers Rhine and Weser, where many suitable waterbodies had arisen from the exploitation of gravel pits.

The occurrence of species in areas that were formerly not populated is also effected by climatic changes. For the first time populations of *Erythromma lindenii* or individuals of *Orthetrum brunneum* have been recorded in the mountainous parts of NRW in the last five years. In addition phenological changes have been observed for many species occurring nowadays much earlier and longer than in the 1980s. But additional factors may also influence the outspread and remain to be analysed in detail.

Comparison of groups of dragonfly species with different areal types due to their inventory development for the time span 1980–2005

Fig. 2 is a depiction of the differentiation between two groups of areal type (Mediterranean species / Eurasian, Westsibirian and Pontocaspian species) and displays the por-

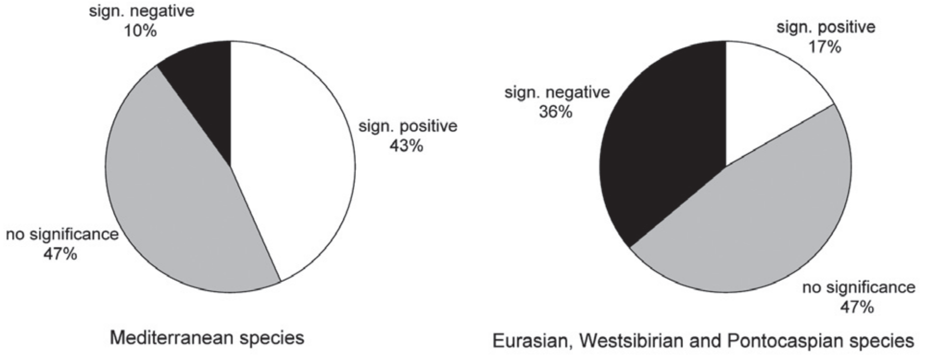

Figure 2. Portion of species with different significant trends in the „areal type groups" of the Mediterranean and the Eurasian, Westsiberian and Pontocaspian species (for the time span 1980–2005).

tion of the species with distinct trends of occurrence (significant positive, significant negative or not significant). In detail, 43% of species with significant increasing trends in their group "Mediterranean species" is clearly higher than in the group of "Eurasian, Westsibirian and Pontocaspian" which is 17%. However with "Eurasian, Westsibirian and Pontocaspian" 36% show a significant negative development. These trends underline a change in species' frequency within favour of the thermophilous species in North Rhine-Westphalia.

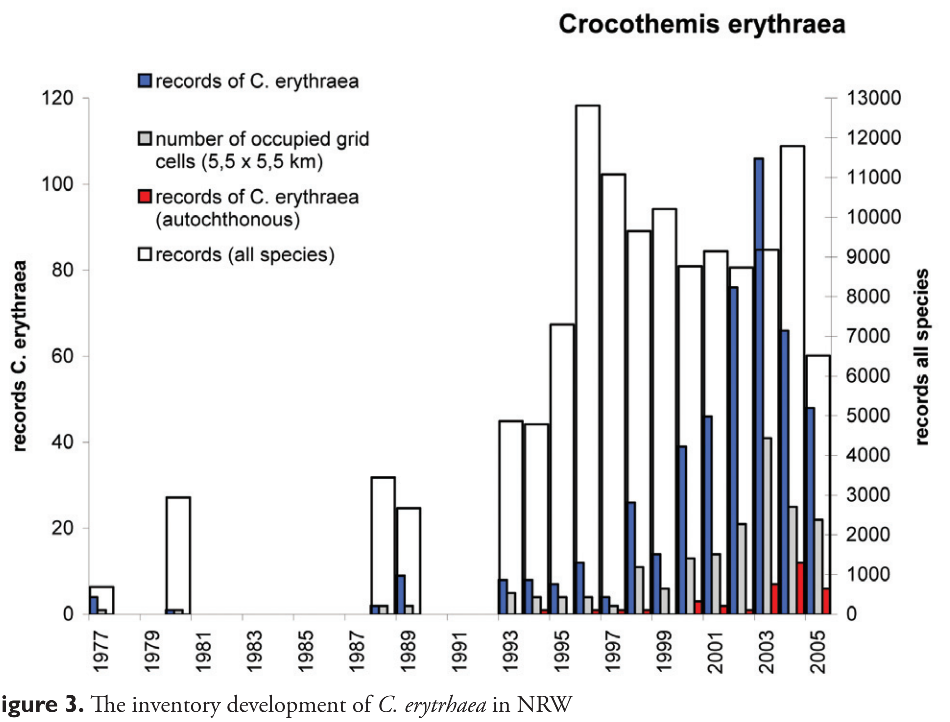

Figure 3. The inventory development of *C. erytrhaea* in NRW

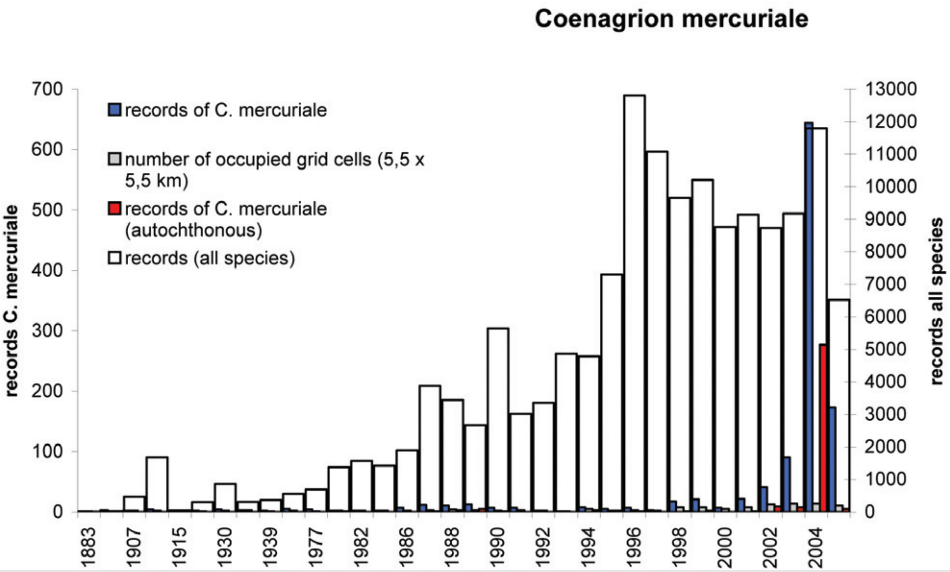

Figure 4. Inventory development for *C. mercuriale* in NRW (additional species-specific investigations in special protected areas started in 2003)

Different examples

A well documented example for the increase and spread of thermophilous dragonfly species is *Crocothemis erythraea* (Ott 1996, 2006, 2007). This species is now widespread in the lowlands of NRW, too. Autochthonous populations have been recorded from several places especially in the area of the Rhineland, where it occurs together with *Coenagrion scitulum* (Rodenkirchen 2004). Particularly this very conspicious and easily determinable species is a good indicator species showing increasing trends affected by climate change (see also figure 3).

The influence of systematic examinations and monitoring programs is shown in figure 4 for *Coenagrion mercuriale*. The erratically increasing numbers of observations in the last years are to be explained by special investigations in connection with the announcement of special protected areas for the "Natura 2000" network of the EU. On the basis of these investigations a thorough knowledge of this endangered species could be gained. But no "real" increase in the populations could be observed. In the Rhineland, an area with a higher average temperature, only one small and very isolated population could be observed. For a long time it has been found in a calcerous springbog. In the "Westfälische Bucht" several partially very large populations are to be found in systems of brooks and ditches. By searching for this species in its best flight period and at typical habitats known for the occurency of this species, some new populations have been observed here in the last years. But an increase of *Conagrion mercuriale* for the reason of climate change cannot be proved.

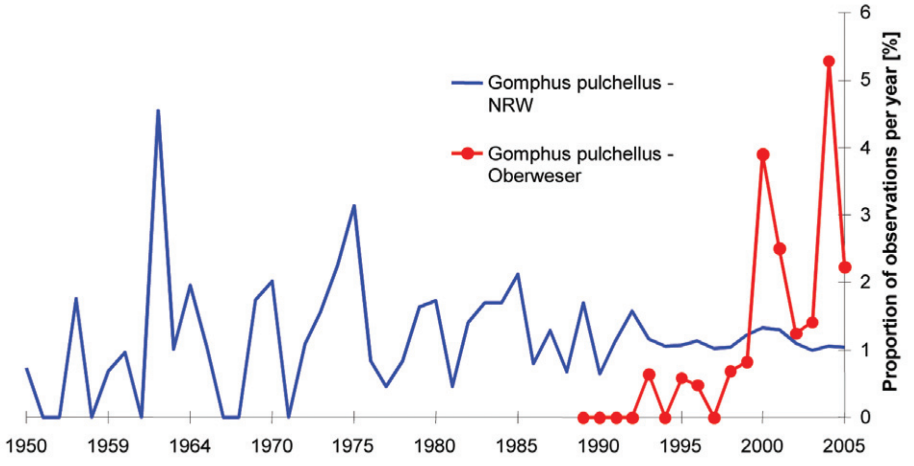

Figure 5. Different developements for Gomphus pulchellus in NRW and the upper valley of the River Weser ("Oberweser")

Regional aspects

For some species the trends of occurrence on the regional level differ from those in the entire country. In Figure 5 different developments for *Gomphus pulchellus* in North Rhine-Westphalia and in the region of the upper River Weser valley ("Oberweser") situated in the east of NRW are presented. For the entire country this species does not show a significant trend in the regarded periods of time. But in the valley of the Weser the species has strongly increased by number of occurrences as well as number of individuals since 1995.

Conclusions

The analysis of trends statistacally tested and based on a large area and long period of time can only be carried out on the basis of extensive data collection. But often additional information and circumstances must be considered to explain trends in occurrence. Therefore the data base of the "AK Libellen NRW" is an important fund which has to be continued and further on interpretated closely in the next years.

The increase of thermophilous species in North Rhine-Westphalia can be proved on the basis of the collected data. The climate change is obviously the most probable reason for it. But there remain other aspects to be regarded, for example the effects of climate change on the whole species inventory (also on the base of regional landscapes), the inter- and intraspecific concurrence, the decrease of supposed "northern" species (for example *S. arctica*), the phenology and the local distribution of species. Therefore not only the data collection has to be continued but also special monitoring programs have to be developed and carried out including currently common species.

Another point will be the investigation of regional differences because these can elucidate the occasional factors.

Acknowledgements

This analysis was only possible by the datarecording of the entire AK Libellen NRW and therefore represents a special example of "teamwork". It is inspired by Dr. J. Ott. Thanks are due to Christina Bantle, Ute Häusler and Wayne Cowan for revising the English version of the manuscript.

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Appendix I

Year of first records of Odonata species in NRW, Spearman rank-order correlation coefficient (Spearman's rho) and its level of significance for the trends of occurring for three regarded periods. In addition the classification of areal types according to St. Quentin (1960), Sternberg (1998) and Sternberg and Buchwald (1999, 2000) is given.

	Year of first record[1]	1850-2005		1980-2005		1996-2005		areal type
Calopteryx splendens	1876	-0,08		**0,52**	**	**0,71**	*	pm
Calopteryx virgo	1872	**-0,75**	*	-0,10		-0,04		ea
Lestes barbarus	1872	-0,37		0,38		-0,58		hm
Lestes dryas	1850	**-0,76**	*	**-0,46**	*	-0,55		ea
Lestes sponsa	1876	0,03		-0,35		-0,36		ea
Lestes virens	1872	**-0,77**	*	**-0,48**	*	0,12		pk
Lestes viridis	1876	0,63		-0,20		**-0,73**	*	atm
Sympecma fusca	1876	**-0,83**	**	**0,41**	*	0,32		hm
Sympecma paedisca	1920	-0,55		.		.		ea
Platycnemis pennipes	1876	-0,13		**0,68**	***	**0,64**	*	pk
Ceriagrion tenellum	1883	**-0,82**	**	-0,34		0,13		atm
Coenagrion armatum	1881	-0,64		.		.		ea
Coenagrion hastulatum	1850	**-0,95**	***	-0,16		0,08		ea
Coenagrion lunulatum	1908	-0,32		**-0,58**	**	0,39		ea
Coenagrion mercuriale	1883	0,12		**0,54**	**	**0,94**	***	atm
Coenagrion ornatum	1986	**0,76**	*	0,29		-0,19		pm
Coenagrion puella	1876	**0,90**	***	**0,64**	***	-0,45		pm
Coenagrion pulchellum	1872	**-0,90**	**	-0,05		0,28		pk
Coenagrion scitulum	1961	0,25		**0,43**	*	0,54		hm
Enallagma cyathigerum	1850	**0,87**	**	0,32		0,27		ea
Erythromma lindenii	1876	0,33		0,20		-0,05		atm
Erythromma najas	1850	**-0,85**	**	-0,18		-0,24		ea
Erythromma viridulum	1877	0,57		**0,58**	**	0,39		hm
Ischnura elegans	1876	**0,87**	**	**0,49**	*	-0,32		ea
Ischnura pumilio	1883	-0,02		**-0,56**	**	0,62		pm
Nehalennia speciosa	1908	-0,55		.		.		ea
Pyrrhosoma nymphula	1876	0,53		-0,12		0,08		ea
Aeshna affinis	1913	0,60		**0,56**	**	0,21		hm
Aeshna cyanea	1876	**0,67**	*	**-0,42**	*	-0,33		pk
Aeshna grandis	1876	**-0,97**	***	**-0,51**	**	-0,03		ea
Aeshna isoceles	1850	**-0,94**	***	**-0,45**	*	0,16		atm
Aeshna juncea	1876	-0,17		**-0,58**	**	0,30		ea
Aeshna mixta	1850	**0,77**	*	-0,04		-0,55		hm
Aeshna subarctica	1926	0,54		**-0,72**	***	-0,30		ea
Aeshna viridis	1930	-0,51		.		.		ea
Anax ephippiger	1989	0,14		-0,02		.		hm
Anax imperator	1876	**0,90**	***	**0,55**	**	-0,52		hm

	Year of first record[1]	1850-2005		1980-2005		1996-2005		areal type
Anax parthenope	1983	**0,85**	**	**0,42**	*	**0,64**	*	pm
Brachytron pratense	1876	**-0,87**	**	0,01		0,31		pk
Gomphus flavipes	1914	0,50		**0,79**	***	0,52		pk
Gomphus pulchellus	1881	0,25		-0,32		-0,26		atm
Gomphus vulgatissimus	1872	-0,59		**0,82**	***	0,57		pk
Onychogomphus forcipatus	1872	-0,46		**0,48**	*	-0,37		pk
Ophiogomphus cecilia	1877	-0,53		**0,54**	**	0,38		ea
Cordulegaster bidentata	1850	0,20		0,10		**0,88**	***	adm
Cordulegaster boltonii	1849	**-0,67**	*	**-0,64**	***	0,35		pk
Cordulia aenea	1872	**-0,78**	*	0,33		-0,36		ea
Epitheca bimaculata	1872	**-0,77**	*	-0,23		.		ws
Oxygastra curtisii	1940	-0,52		.		.		atm
Somatochlora arctica	1908	-0,12		**-0,38**	(*)	0,04		ws
Somatochlora flavomaculata	1907	-0,33		-0,22		0,01		ea
Somatochlora metallica	1850	**-0,75**	*	-0,35		-0,12		ws
Crocothemis erythraea	1977	**0,86**	**	**0,82**	***	**0,88**	***	hm
Leucorrhinia albifrons	1941	-0,50		.		.		ea
Leucorrhinia caudalis	1888	**-0,76**	*	.		.		ws
Leucorrhinia dubia	1877	**-0,88**	**	**-0,74**	***	-0,30		ea
Leucorrhinia pectoralis	1877	**-0,95**	***	-0,32		0,06		ea
Leucorrhinia rubicunda	1849	**-0,85**	**	-0,21		0,22		ea
Libellula depressa	1876	0,62		**-0,56**	**	-0,43		pm
Libellula fulva	1907	0,42		0,18		-0,48		pm
Libellula quadrimaculata	1862	**0,67**	*	0,27		-0,21		ea
Orthetrum brunneum	1888	0,16		**0,42**	*	-0,21		hm
Orthetrum cancellatum	1876	**0,78**	*	**0,49**	*	-0,53		hm
Orthetrum coerulescens	1883	**-0,80**	**	0,09		0,52		atm
Sympetrum danae	1876	0,45		**-0,65**	***	0,24		ea
Sympetrum depressiusculum	1876	**-0,93**	***	-0,18		-0,54		ea
Sympetrum flaveolum	1876	**-0,77**	*	-0,36		-0,05		ea
Sympetrum fonscolombii	1872	0,06		0,37		-0,51		hm
Sympetrum meridionale	1930	0,23		**0,50**	**	0,25		hm
Sympetrum pedemontanum	1980	**0,73**	*	**-0,66**	***	-0,35		ea
Sympetrum sanguineum	1876	**0,87**	**	**0,48**	*	**-0,67**	*	hm
Sympetrum striolatum	1872	0,27		0,27		**-0,75**	*	hm
Sympetrum vulgatum	1850	-0,27		**-0,76**	***	-0,55		ea

[1] Year of first record; if not mentioned in the referred publication, the date of publication is given

Level of significance
extra bold: significant correlation (P<0,05)
***** 0,01<P<0,05
****** 0,001 <P<0,01
******* P<0,001

Areal types
adm adriatomediterranean
atm atlantomediterranean
ea eurasian
hm holomediterranean
pk pontocaspian
pm pontomediterranean
ws westsibirian