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No bird soars too high,
if he soars with his own wings.

William Blake

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Abstract

Global warming is a contemporary issue which has an impact on all kinds of creatures. Many studies about birds examined the effects of climate change and postulate that changes in morphology could be a response to worldwide increasing temperatures. The present diploma thesis investigates whether five common aerial predators Goshawk (*Accipiter gentilis),* Sparrowhawk *(Accipiter nisus)* Buzzard *(Buteo buteo), Kestrel (Falco tinnunculus), and Tawny Owl (Strix aluco*) show changes in morphology over the period from 1880 to 2015 in Central Europe due to global warming over that time. These aerial predator species belong to the families Accipitridae, Falconidae and Strigidae. Basis for the morphological measurement were study skins which had been provided by the Museum of Natural History Vienna (NHMW) and the Biologiezentrum Oberösterreichisches Landesmuseum (Linz). Altogether 7 morphological characteristics at 1080 museum study skins from northern and eastern Austria were measured. The sample size was split in 4 categories (male, female, adult, juvenile) per species. Using charts, regression models and Pearson correlation coefficient, dependences between individual and year, individual and temperature as well as correlations between all measured morphological traits were analysed. The results gave no hint about the influence of climate change to morphology and surprisingly there were no significant correlation neither between morphological characteristics of the bird specimen and year, nor between morphological characteristics and temperature. But four of the five species showed significant correlations between morphological characteristics. Number of correlations between morphological traits was highest in bird feeding specialist (Goshawk, Sparrowhawk) and lowest in generalist species (Common Buzzard, Kestrel, Tawny Owl). Eco-morphological adaptations may be connected also to other environmental factors (e.g., long-term habitat changes, changes in food availability) and therefore future studies should consider such factors more.

Zusammenfassung

Klimaerwärmung ist ein sehr aktuelles Thema und beeinflusst Lebewesen auf unterschiedliche Art und Weise. Viele Studien haben sich mit globaler Erwärmung auseinandergesetzt und den Zusammenhang zwischen weltweitem Temperaturanstieg und morphologischen Veränderungen bei Vögeln erforscht. Die folgende Diplomarbeit untersucht, ob sich die Morphologie fünf heimischer Beutegreifer Habicht (*Accipiter gentilis),* Sperber *(Accipiter nisus),* Mäusebussard *(Buteo buteo),* Turmfalke *(Falco tinnunculus)* und Waldkauz (*Strix aluco*) über den Zeitraum 1880 – 2015 sowie in Abhängigkeit von der Klimaerwärmung in Mitteleuropa in den vergangenen 135 Jahren verändert hat. Die untersuchten Beutegreifer gehören zu den systematischen Familien der Accipitridae, Falconidae und Strigidae. Die Grundlage der Messungen waren Museumsbälge, welche vom Naturhistorischen Museum Wien (NHMW) und dem Biologiezentrum Oberösterreichisches Landesmuseum (Linz) zur Verfügung gestellt worden sind. Insgesamt wurden 7 morphologische Merkmale an 1080 Museumsbälgen aus Nord- und Ostöstereich vermessen. Die gesamte Stichprobe wurde in 4 Kategorien (männlich, weiblich, adult, juvenil) unterteilt. Mittels graphischen Darstellungen, Regressionsmodellen und Pearson-Korrelation wurden Abhängigkeiten und Zusammenhänge zwischen Jahr und Individuum, Temperatur und Individuum sowie den einzelnen Merkmalen untereinander untersucht. Überraschenderweise zeigen die Ergebnisse keine signifikanten Zusammenhänge zwischen Jahr und morphologischen Merkmalen sowie Temperatur und morphologischen Merkmalen auf. Vier der fünf untersuchten Arten zeigen signifikante Korrelationen zwischen den einzelnen morphologischen Merkmalen. Die meisten Korrelationen wurden zwischen den Merkmalen der, auf Vogeljagd spezialisierten, Arten (Habicht, Sperber) gefunden während Generalisten (Mäusebussard, Turmfalke, Waldkauz) deutlich weniger Zusammenhänge zwischen den Merkmalen aufweisen. Veränderung von morphologischen Eigenschaften kann auch durch andere Faktoren beeinflusst sein. Daher sollten zukünftige Untersuchungen den Einfluss weiterer Umwelteinflüsse (z.B. Habitatveränderung, Veränderung des Beuteangebotes) auf Beutegreifer berücksichtigen.

Introduction

Global warming is a contemporary issue and climate change has already and will have a major impact on all kinds of creatures in the future(Millien et al., 2006; Root et al., 2003; Scheifinger et al., 2005; Walther et al., 2002). Rising mean temperature causes shifts in the growing season of plants and the life cycle of animals, most extremely in middle and high latitudes. Flora and fauna reacts to global warming with changes such as early blossoming, coverage of new areas, changes in shape, stand density and physiology and even with extinction (Hughes, 2000; Koch, 2010; Maurer et al., 2009; Menzel et al., 2006; Scheifinger et al., 2005; Walther et al., 2002). Especially mammals and birds are well analysed and some authors claim that morphological changes and decline in body size could be one of many responses to global warming (Berthold, 1998; Gardner et al., 2014; Jakober & Stauber, 2000; Millien et al., 2006; Salewski et al., 2014; Sheridan & Bickford, 2011; Smith & Betancourt, 2006). Body size is connected to energy balance and thermoregulation. Therefore, every change in body size also has an effect on water and energy requirements. Facing the issue of global warming, body size may be a decisive factor for the resilience of species in the future (Calder, 1985; McKechnie & Wolf, 2010; Porter & Kearney, 2009; Scholander et al., 1950). Bergmann's rule describes the principle of different body sizes in endotherms. Populations or species which appear in cold regions are bigger than those which live in hot areas. Thus, larger individuals have a more advantageous surface area to volume ratio than small individuals, which results in a thermoregulation that is perfectly adapted to their respective habitat. Also small individuals, which are facing the danger of overheating, can give off heat quicker than their larger relatives (Temple, 2001).

Due to worldwide research areas, many studies yield in inconsistent results. While some researchers say that decreasing body size is influenced by global warming, others cannot find definite proof for that hypothesis. (Gardner et al., 2014; Reside et al., 2015; Salewski et al., 2014; Sheridan & Bickford, 2011; Teplitsky & Millien, 2014; Van Buskirk et al., 2010; Yom-Tov & Yom-Tov, 2006; Yom-Tov et al., 2006).

Climate change since 1880

Long term studies show that climate has changed conspicuously over the last few decades. However, global warming has not been linear during the past hundred years. In the 20th century the average global temperature has increased in total by almost +1 °C. Presumably, the main cause for the rise of temperature cannot be assigned to natural causes, such as solar radiation or volcanic activity. It is more likely that the explosive increase of greenhouse gas emissions through human activity is assumed to be responsible for the rise of temperature. (Auer et al., 2007; Böhm et al., 2009; Brohan et al., 2006; Crowley, 2000; Jones et al., 1999; Solomon et al., 2007).

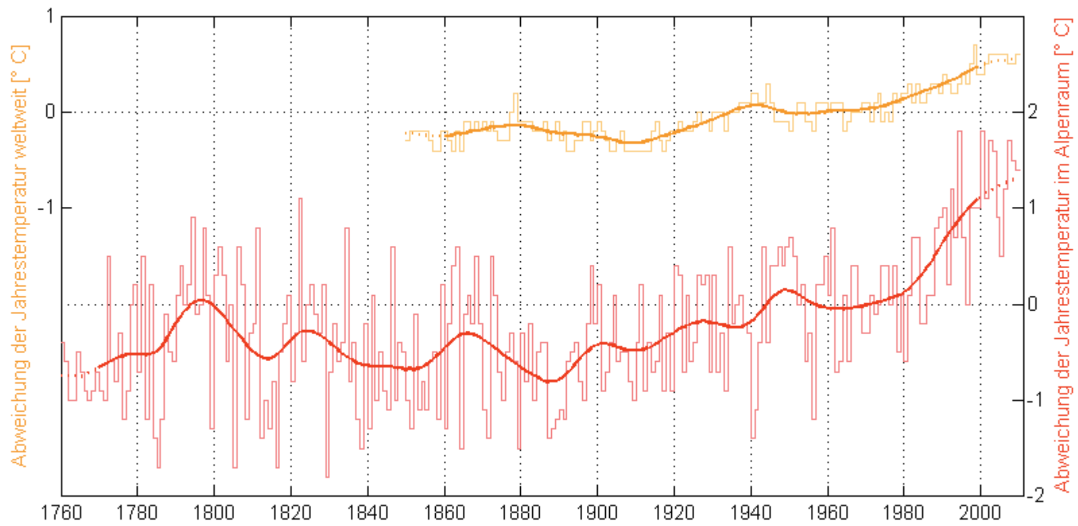

Figure 1: Development of mean annual temperature 1850-2009 worldwide (orange, left y-axis) and the Greater Alps 1760-2009 (red, right z-axis). Shown are annual deviations from the average of the years 1901-2000 and their smoothed trends (Auer et al., 2007; Brohan et al., 2006; Jones et al., 1999) Zugriff: 18.03.16 http://www.zamg.ac.at/cms/de/images/klima/bild_ip-klimawandel/klimavergangenheit/neoklima/3-2-1_1_global-gar

Relatively well documented is the globally development over the past 160 years (Fig. 1, orange line). The 2nd half of the 19th century until the 1920ies was characterized by a widely stable temperature considerably below the temperature today. This period was followed by an increase until the 1940ies. Another constantly period lasted until the 1970ies. Since then temperature increased extensively until the present. The 1990s were the warmest decade with a deviation of +0.38°C compared to the mean temperature of the whole 20th century. Furthermore, ground-level atmosphere has risen again by +0.19°C in the first decade of the 21st century. However, this development shows regional variations. There are regional deviations from the global warming trend. The present thesis concentrates on a special region in Central

Europe, covering Northern and Eastern Austria. The red line (Fig. 1.) displays the temperature development in the Greater Alps region from 1760-2009. It is one of the regions in which the temperature increase was nearly twice as high compared to the average global mean temperature. However, the temperature increase did not occur continuously, but shows periods with both rising and decreasing temperatures. While there was a short warming phase at the end of the 18th century, the 19th century is marked by a weak cooling period. In the 20th century, temperature was rising gradually. The first five decades are distinguished by rising temperatures followed by a temporary cooling until 1970. From the 1980s onwards temperature has been rising rapidly, which is partly connected to the economic development. The warming period in the early 20th century was caused by industrialization and can be seen as a change-over from a naturally influenced climate to a human influenced climate. (Auer et al., 2007; Brohan et al., 2006; Crowley, 2000; Jones et al., 1999; Solomon et al., 2007).

Aims of the study

Previous studies examined changes of morphology and body size in various bird species throughout the world (Gardner et al., 2014; Salewski et al., 2014; Yom-Tov & Yom-Tov, 2006; Yom-Tov et al., 2006). The present diploma thesis tries to find out if (1) five common aerial predators (Northern Goshawk *Accipiter gentilis*, Eurasian Sparrowhawk *Accipiter nisus*, Common Buzzard *Buteo buteo*, Eurasian Kestrel *Falco tinnunculus* and Tawny Owl *Strix aluco*) show a change of morphological characteristics over the period 1880 – 2015 and due to climate change over the same time. Analyses were both conducted for all aerial predators together, as well as separate for every single species. (2) Furthermore, a division in age and sex was made to find out if changes in morphology differed in males and females as well as in juveniles and adults.

Birds of prey and owls as aerial predators

A predator is an animal which hunts and feeds on other animals. In the present case aerial predators are defined as bird groups (Accipitridae 3 species; Falconidae 1 species, Strigidae 1 species) which are characterized by hunting and killing prey in order to survive. Due to their lifestyle and to the environmental conditions they live in, many morphological adaptations have developed. The most remarkable adaptations can be found in bill, feet, wings and eyes (Ferguson-Lees & Christie, 2001; Anita Gamauf, 2016 in press; Génsbøl, 2008). From the scientific point of view, these characters can be subdivided into (I) "flying apparatus", (II) "feeding" and (III) "killing apparatus" (A. Gamauf, Preleuthner, & Winkler, 1998). Raptors have conspicuously hooked bills with a clearly longer upper mandible than the lower. The sharp edges of the mandibles allow them to skin or pluck their prey easily (Génsbøl, 2008; Mebs & Schmidt, 2014). Falcons and owls are also able to kill their prey (e.g. rodents, small birds) with the bill by biting them into the head or neck. The feet are particularly adapted for catching and killing. The form of the talons clearly suits their habits. Depending on prey categories and hunting methods, body shape is highly variable (Brown, 1976; Anita Gamauf, 2016 in press; Mebs & Schmidt, 2014). The legs (tarsus)can be either short with strong toes and talons (e.g. *B. buteo*), mainly when prey is killed on the ground, or long with razor-sharp claws, when prey consists of birds which are pursued and caught in the air (e.g. *A. nisus*), but there are many intermediates, too. Raptors have four toes, three of them directed foreword and one backward. Due to the reversed toe they can grasp and hold captured prey effortlessly. (Génsbøl, 2008; McGowan, 2004; Mebs & Schmidt, 2014). Broad wings and a powerful tail combined with an excellent visual acuity makes it possible to soar in the air and spot prey even at great heights. Individuals with long pointed wings, such as hawks, are fast and skilful hunter (Génsbøl, 2008). The five examined species belong to three different taxonomic families: Accipitridae, Falconidae and Strigidae (Dickinson & Remsen Jr., 2013; Ferguson-Lees & Christie, 2001; Wink et al., 2008).

Fact sheet: Northern Goshawk (*Accipiter gentilis*)

Figure 2: left. adult Goshawk. (Photo: R. SCHMIDT in Mebs & Schmidt, 2006, p.294)

Figure 3: right. Juvenile Goshawk (Photo: J. DIEDRICH in Mebs & Schmidt, 2006, p.292)

The Northern Goshawk is a member of the species-rich family Accipitridae. Within this species, difference in size is obvious, so called sex-dimorphism. Females weight about 1200g and can reach a wing-span of 120cm while the males are clearly smaller with a weight of circa 700g and a wing-span of maximum 105cm (Kenward, 2006; Mebs, 2012; Svennsso et al., 2011).
The plumage of immature goshawks is dark brown on the dorsal side and the belly is yellowish buffy and heavily streaked (Fig. 3 & 4). Adult goshawks, in contrast, have a white belly with dark horizontal bars and a bluish grey upper side is (Fig.2). Characteristic for this raptor species is its long tail as well as its short, broad and rounded wings. Young birds have yellow eyes and a pale eyebrow stripe, while adult birds have yellow-coloured eyes and a white eye stripe (Fig.2). The older they are their eyes become more red-coloured (Kenward, 2006; Mebs & Schmidt, 2014).
The distribution area of the Northern Goshawk includes Europe, a wide zone from Northern Asia to the Pacific Ocean and the forested region of North America. It inhabits coniferous forests as well as deciduous woodland and prefers large mature forests to breed in. But it also can be found in smaller woods and even urban areas (Hardey et al., 2009; Kenward, 2006; Mebs & Schmidt, 2014). The Northern Goshawk is a powerful and fast hunter. Its prey consists mostly of birds but also of small mammals up to rabbit (*Lepus spp.*) and pheasant (*Phasianus*

colchicus) size. They are sit-and-wait hunters but also attack their prey in a steep dive (Kenward, 2006; Svennsson et al., 2011).

Figure 4: Juvenile Goshawk in flight. (Photo: M. SCHÄRF in Mebs, 2012, p. 128)

Their nests are constructed using twigs and branches and are mostly built in mature woods. Goshawks often re-use the nests several times before they build a new one or refurbish an already existing one. In Central Europe, normally the Northern Goshawk is a resident which occupies its home range the whole year round; only individuals from northern regions dispense southwards during winter (Hardey et al., 2009; Kenward, 2006).

Fact sheet: Eurasian Sparrowhawk (*Accipiter nisus*)

Figure 6: Juvenile Sparrowhawk (Photo: G. WENDL in Mebs & Schmidt, 2006, p.309)

Figure 5: Adult female Sparrowhawk in flight. (Photo: M. GRIMM in Mebs, 2012, p. 138)

The Eurasian Sparrowhawk is a small raptor species belonging to the family of Accipitridae. The difference in size between males and females is extreme. The male weights 140g on average and has a wing span up to 62cm. The female is clearly larger than the male with a wing span of up to 74cm and a weight of around 280g. (Mebs & Schmidt, 2014; Newton, 1986; Svennsson et al., 2011) The Eurasian Sparrowhawk is often confused with the Northern Goshawk, but there are a lot of characteristics that can help to distinguish those two birds e.g. absolute size and weight, shape as well as flight speed and mode. Sparrowhawks are adapted to forested habits and have therefore short and rounded wings, as well as a short neck (Fig. 6). It is characterised by a longer and more rectangular tail compared to the rounded one of a Goshawk. All in all, the Sparrowhawk has a rounder and slimmer shape than the Goshawk. Both species also show difference in flight. Its flight path is wavelike and the wing beats of the Eurasian Sparrowhawk seem more hurried than the Goshawk's wing beats (Génsbøl, 2008; Newton, 1986; Svennsson et al., 2011).

Due to their diet, Sparrowhawks have long thin legs (tarsi) with long toes. Males have a bluish-grey colour on its dorsal side and barred, reddish brown underparts (Fig. 7). Females are not so contrasting having grey-brown backs and a much lighter belly with dark bars on it. Immature birds are brown on the upper side and the tips of the feathers are much paler than the rest of the body. Their bellies are light with irregular bars (Fig. 5) (Génsbøl, 2008; Mebs & Scherzinger, 2000; Mebs & Schmidt, 2014; Newton, 1986; Svennsson et al., 2011).

The Eurasian Sparrowhawk can be found nearly everywhere throughout Europe with the exception of Iceland, the Northern region of Scandinavia and Russia. Eastwards the distribution range reaches to the Pacific Ocean and Japan. A subspecies of the Eurasian Sparrowhawk even inhabits an isolated region in the Himalayas (Génsbøl, 2008; Mebs & Schmidt, 20014).

It prefers woodland with mixed or coniferous forests to breed in, but it can also be found in parks, cemeteries and urban areas. Sparrowhawks nest mainly in coniferous trees building new nests every year. The female builds the nest for the most part by collecting small twigs and branches (Génsbøl, 2008; Hardey et al., 2009; Mebs & Schmidt, 2014; Newton, 1986). There is a strict division of labour between males and females during breeding season. The female is responsible for incubation and guarding the nestlings against weather conditions and enemies (e.g. pine marten, owls) while the male provides the family with food (Mebs & Schmidt, 20014). The Sparrowhawk hunts in woodland as well as in open country and is specialized on small birds. It hunts by sitting and waiting or surprises its prey by flying low next to hedges and tree rows (Forsman, 1991; Newton, 1986). It pursues its prey fast and skilfully and is, for the most part, very successful on its foray (Forsman, 1991). Young Sparrowhawks from Northern Europe, mainly young birds, are migratory and leave their territories in autumn to spend the winter in Central Europe or even in North Africa. Those in Central Europe are resident and remain in their breeding territories throughout the year (Génsbøl, 2008; Newton, 1986; Schmidt et al., 2014).

Figure 7: adult male Sparrowhawk. (Photo: J. DIEDRICH in Mebs & Schmidt, 2006, p.306)

Fact sheet: Common Buzzard (*Buteo buteo*)

Figure 8: left. Perching immature Buzzard. (Photo: M. SCHÄRF in Mebs, 2012, p. 173)

Figure 9: right. Immature Buzzard in flight.
(Photo: M. SCHÄRF in (Mebs, 2012, p. 174)

The Common Buzzard is medium-sized, belongs to the Family of Accipitridae and is in many parts of Europe the most numerous bird of prey species. Sex-dimorphism is not very distinctive and females are generally a little bit larger than the males with a weight of about 990g. Males weight on average 790g but distinction is only possible when both sexes are seen in the immediate vicinity to each other. Morphologically, they overlap to a large extend. The Common Buzzard has a short broad tail and broad wings with a wingspan of 115-138 centimetres (Mebs & Schmidt, 2014). The plumage varies from almost completely white to almost dark brown and is independent from sex and age (Fig. 8). Normally dark individuals are more barred on breast and belly than pale ones (Forsman, 1991; Génsbøl, 2008). Adult Buzzards have a broad blackish sub-terminal tail band and many narrow bars. The belly and breast is barred and wings follow the same pattern. Contrary to this, the sub-terminal tail band and the trailing edges of juveniles are diffuse and the breast is lengthwise striped. Furthermore, juveniles have a yellowish-amber iris compared to the dark brown one of adult individuals (Fig. 10) (Génsbøl, 2008; Hardey et al., 2009; Mebs & Schmidt, 2014; Svennsson et al., 2011).

As already mentioned, the Common Buzzard inhabits nearly all habitat types from West Europe, West Siberia, Asia Minor, the Caucasus and North Iran (Génsbøl, 2008; Mebs & Schmidt, 2014; Riesing et al., 2003). It can be found throughout all landscapes and prefers small woods to breed in and open areas, such as fields and pasture, to hunt. They normally build their nests in old trees close to the forest edge. But they also can nest on cliffs and even on the ground in moorland without any trees. Common Buzzards can often be seen perching next to roads, where they can easily feed on road kills (Génsbøl, 2008; Hardey et al., 2009; Mebs & Schmidt, 2014).

The Common Buzzard is mainly a sit-and-wait hunter observing its surroundings for prey from an exposed point. Under windy conditions it is able to hover like a Kestrel (Fig. 9). Where ground vegetation is short cut, it walks around on the ground, looking for small prey like earthworms and beetles. The Common Buzzard is an opportunist. Its diet consists mainly of small mammals such as voles (*Microtus spp*.) and mice (*Apodemus spp*.), but also contains small birds, nestlings, reptiles, amphibians, carcasses, insects and earthworms (Forsman, 1991; Mebs & Schmidt, 2014).

Northern populations are long-distance-migrants (*B. buteo vulpinus*), while Buzzards from Central Europe are mostly residents and only partial migrants. Adult Buzzards are mainly resident, while juveniles are more mobile. The northern populations (*B. b. buteo*) spend the winter in Central and South Europe (Forsman, 1991; Génsbøl, 2008; Mebs & Schmidt, 2014; Schmidt et al., 2014).

Figure 10: Change of iris-colour with age: Juvenile left, Adult right (Photo: D. FORSMAN in Forsman, 1999, p. 11)

Fact sheet: Eurasian Kestrel (*Falco tinnunculus*)

Figure 11: left. Adult male Kestrel (Photo: G. WENDL in Mebs & Schmidt, 2006, p.457)

Figure 12: right. Adult female Kestrel (Photo: P. ZEININGER in Mebs & Schmidt, 2006, p.460)

The Eurasian Kestrel is a small predator of the family Falconidae. It is widespread in Europe, Asia, Africa and many Atlantic Islands (Génsbøl, 2008; Glutz von Blotzheim et al., 1989). The female is slightly bigger and weighs about 230g while males weight maximally 200g (Mebs & Schmidt, 2014). The wing span vary from 68cm to 82cm. Kestrels have long tails and narrow pointed wings. They have a short neck and a strong beak with a characteristic notch on the top edge of the beak called "tomial tooth" (Génsbøl, 2008; Svennsson et al., 2011; Village, 1990).

They display a conspicuous sexual dimorphism in colour and pattern. Adult males can be distinguished from females by their bluish-grey tail with broad black sub-terminal bar (Fig. 11). Females have a brown ground colour with intensively barred tails (Fig. 12). Both sexes have malar stripes and a rufous back, which is spotted in males and striped in females. Furthermore, they have buffy underparts with drop-shape spots.(Génsbøl, 2008; Glutz von Blotzheim et al., 1989; Village, 1990). Juveniles are similar to adult females and not easy to distinguish.

Besides dense and extensive forests the Eurasian Kestrels occurs in nearly every habitat. It prefers open areas with sufficient prey but can also be found in urban areas, tundra, semi-deserts, cliffs, parks and many more. (Forsman, 1991; Génsbøl, 2008; Hardey et al., 2009; Mebs & Schmidt, 2014). Kestrels use old nests of other birds (e.g. corvids, birds of prey) or breed in tree or cliff hole. Nests can also be found on buildings such as churches and ruins. They are very tolerant towards human disturbance and can even breed in the city centre (Forsman, 1991; Génsbøl, 2008; Mebs, 2012; Sumasgutner et al., 2014).

Kestrels mainly hunt small mammals, especially rodent. They also prey on large insects (grass-hoppers, beetles), reptiles, amphibians and earthworms but only as supplement to its common diet. Small birds, mainly nestlings and young, are also taken as prey, especially when rodents are scarce. (Forsman, 1991; Glutz von Blotzheim et al., 1989; Sumasgutner et al., 2014; Village, 1990).

The Kestrel hunts in a very characteristically way by hovering at a height of 10-50 m above the ground (Fig. 13). Once prey is spotted, it makes a steep dive towards its target and kills it by biting it into head or neck. They also hunt on the ground or by perching on electricity poles and trees (Forsman, 1991; Génsbøl, 2008; Village, 1990). Hunting methods vary during the seasons, especially during cold weather conditions Kestrels act as sit-and-wait predators to save energy, whereas in summer they practise more flight-hunting (Mebs & Schmidt, 2014; Village, 1990). Northern and eastern European populations migrate and winter in South Europe and Northern Africa. Populations from Central Europe are mainly resident or partly migratory (Schmidt et al., 2014). After leaving the nest, juveniles have a wider dispersion than adult individuals. Depending on weather, migratory individuals return home in March and April (Forsman, 1991; Génsbøl, 2008; Kreiderits, 2015; Mebs & Schmidt, 2014; Svennsson et al., 2011).

Figure 13: Male adult hovering.
(Photo: SILVESTRIS / GROSS in Mebs & Schmidt, 2006, p.459)

Fact sheet: Tawny Owl (*Strix aluco*)

Figure 14: Brown individual (Photo: SCHENDL in Mebs & Scherzinger, 2000, p. 228)

Figure 15: Grey specimen. (Photo: REINHARD in Mebs & Scherziner, 2000, p. 227

The Tawny Owl is a medium-sized earless owl belonging to the family of Strigidae. It is the most common owl in Europe and due to its adaptability it can be found nearly everywhere from northern Africa to China, but they are absent in Ireland, Iceland and northern Scandinavia (Glutz von Blotzheim & Bauer, 1980; Hardey et al., 2009). With a weight of 440g the male is normally slightly smaller than the female, which weighs about 560g. Sexing females and males on size and weight is nearly impossible because of the high morphological overlapping ranges. (Melde, 1989; Mikkola & Lamminmäki, 2014). The wing span varies from 93cm – 98cm in both sexes (Mebs & Scherzinger, 2000).

The Tawny Owl is a compact looking species which has a round head without ear-tufts a short tail and broad, round wings. It has large blackish-brown eyes and the yellowish bill has bristles on the base. (Mebs & Scherzinger, 2000; Mikkola, 2012; Svennsson et al., 2011).

The plumage colour is very variable among specimen. Even chicks from the same brood can show different plumage colours in. Basic plumage coloration is grey, rufous or brown and are independent of sex or age. Brown morph occurs more often in warm and humid areas while rufous and grey morphs appear rather in cold and dry regions (Glutz von Blotzheim & Bauer, 1980; Hardey et al., 2009; Melde, 1989). All morphs have streaky cryptic plumage, which has pale underparts and a light facial disc with whitish eyebrows. Colour and pattern gives them a cryptic appearance. Shoulders and wings are often dotted white (Mebs & Scherzinger, 2000; Mikkola, 2012; Svennsson et al., 2011).

Like other owl species, the Tawny Owls does not build own nests, but reuse old nests of other species such as birds of prey and corvids (mostly carrion crow, [*Corvus corone*]). But they also use old deciduous trees, such as oaks with spacious holes, to breed in. As long as there are old trees, the Tawny Owl can be found in woods as well as in settlement areas, cemeteries, parks and gardens. When trees are absent, it also can breed in buildings and nest-boxes. (Glutz von Blotzheim & Bauer, 1980; Hardey et al., 2009; Mebs & Scherzinger, 2000; Svennsson et al., 2011).

Figure 16: rufous Tawny Owl. (Photo: C. TOWNEND in Mikkola, 2012, p. 310)

It is a crepuscular and nocturnal bird which spends the days resting in one of its many hiding places. (Glutz von Blotzheim & Bauer, 1980; Mebs & Scherzinger, 2000). It mainly hunts by perching and due to its soft feathers it attacks its prey silently. Its diet composition is highly variable and differs from location to location. It mainly lives on small mammals, birds, insects and amphibians. When preferred mice and voles are not available, proportion of birds is higher. The Tawny Owl has an inborn hunting behaviour- when prey is localized, it grabs its target with its talons and kills it by biting its prey into head or neck. It also hunts in flight and due to its short tail and short broad wings it can easily manoeuvre in woodland (Glutz von Blotzheim & Bauer, 1980; Mebs & Scherzinger, 2000; Mikkola, 2012).

The Tawny Owl is a non-migratory species which is sedentary in its territory throughout the year. After flying off, young individuals stay in the surroundings and try to find a vacant territory (Mebs & Scherzinger, 2000).

Material and methods

Study area

All investigated specimens were collected in Northern and Eastern Austria between about 47.7°N and 49.0° N and between about 12.95° E and 17.05° E, respectively the study area is southward delineated by the Alps and overlaps with Northeast climate region (red circle, Fig. 18.). According to measuring stations of ZAMG, the study area belongs to a region with a relatively homogenous climate variation (green dots, Fig. 18). All specimens were collected between 1880 and 2015 in these areas. (ZAMG, HISTALP Station Map of the Greater Alpine Region, 2012, http://www.zamg.ac.at/histalp/project/maps/station_map.php). All meteorological data were provided by ZAMG. For the evaluation I used the temperature mean per year for the same time-period 1880-2015.

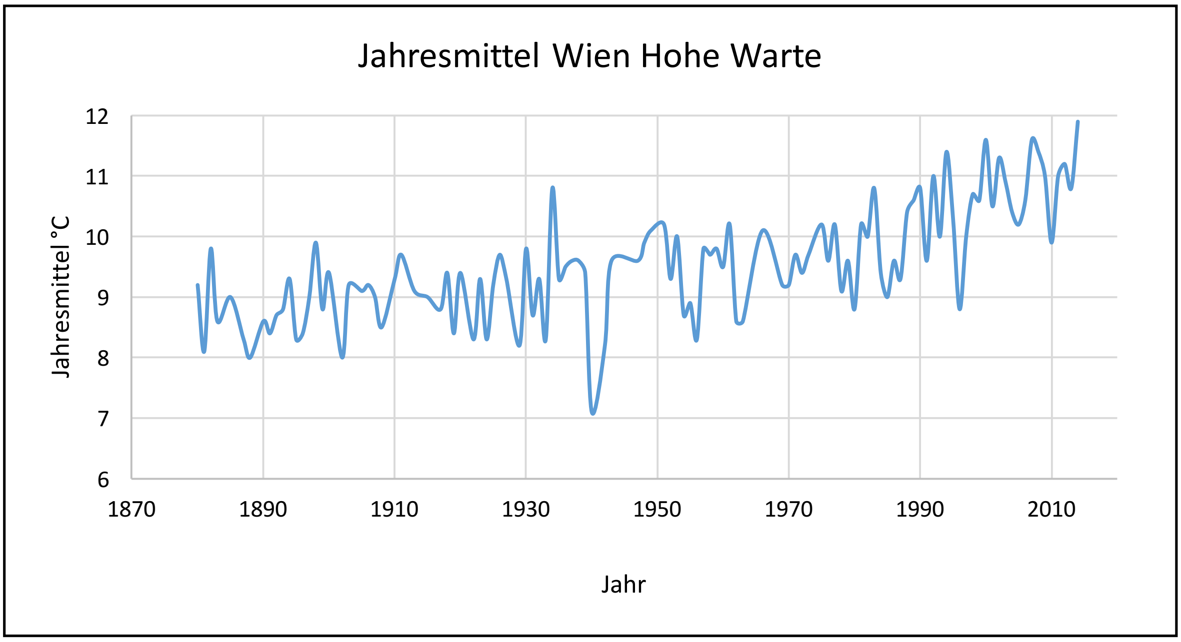

Figure 17: Mean temperatures from 1880 - 2014 in Vienna and the surrounding areas (Gorgon, 2015).

Figure 17 represents the the climate conditions in Vienna and the surrounding areas over the last 135 years. This chart demonstrates very well, that climate change has not been linear during the last decades. As also seen in Fig. 1., there have been periods of both rising and decreasing temperatures, and what also can be seen, is a trend of rising mean temperature from the 1980s on.

Selection of study species

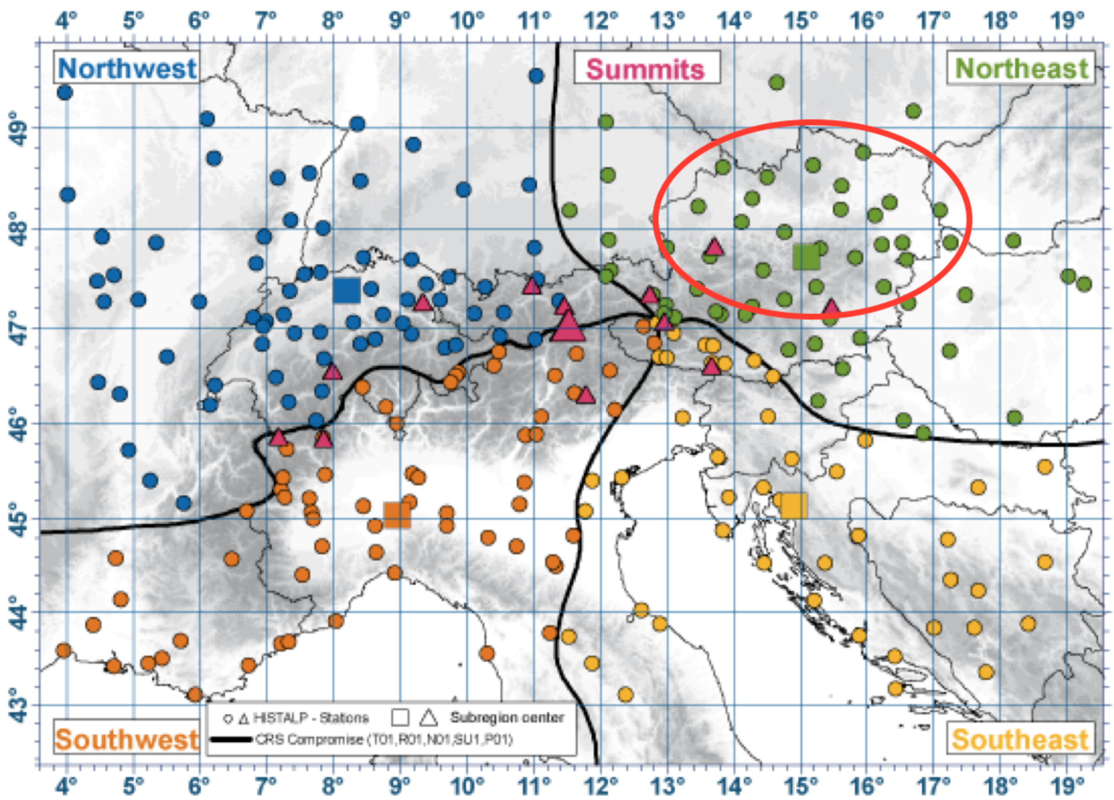

Figure 18: Study area with different climate variation areas. (ZAMG, HISTALP Station Map of the Greater Alpine Region, 2012, http://www.zamg.ac.at/histalp/project/maps/station_map.php)

Five raptor species from three families (see fact sheets) that are widely distributed in Austria and common in both scientific museums were selected. They cover the period from 1880 to 2015. The selected species were provided by the *Natural History Museum Vienna* (NHMW) and *Biologiezentrum Linz*. For each species, I examined between 113 and 382 study skins. In total, sample size contained 1080 specimens. Specimens were excluded when they did not meet the criteria for certain analyses (Tab. 1). Since the size of morphological traits may vary with age and sex, I recorded both categories for each single specimen (Freeman & Jackson, 1990; Salewski et al., 2014). Thus, sample size was split into the following four categories: female, male, adult and juvenile. Additionally, I noted the year of collection of each specimen. The sample size comprised 113 Northern Goshawks, 382 Eurasian Sparrowhawks, 277 Common Buzzards, 125 Eurasian Kestrels and 183 Tawny Owls (Tab. 1).

Table 1: Number of examined specimens.

	Northern Goshawk	Eurasian Sparrowhawk	Common Buzzard	Eurasian Kestrel	Tawny Owl
Female	54	214	139	64	100
Male	53	165	119	57	80
Adult	42	165	141	85	83
Juvenile	65	214	117	36	97
n	**107**	**379**	**258**	**121**	**180**
Adult female	28	93	72	40	42
Adult male	14	72	69	45	41
Juvenile female	26	121	67	24	58
Juvenile male	39	93	50	12	39
n	**107**	**379**	**258**	**121**	**180**

Morphological measurements

Many studies have discussed which measurements represent body size the best. Some claim that tarsus length is an adequate surrogate for body size while, others say that wing length is a better predictor, and still others use multivariate measures as an estimate of body size (Freeman & Jackson, 1990; Gosler et al., 1998; Hogstad, 2011; Rising & Somers, 1989; Salewski et al., 2014; Senar & Pascual, 1997; Yom-Tov & Yom-Tov, 2006). Due to the measurements of museum skins, it was impossible to get the body mass of each bird. Therefore, a surrogate for body size was needed.

Here, altogether 7 different morphological traits were measured. In order to avoid biased measuring, all measurements were carried out by a single person. Using the instructions of Eck et al. (2011) in the "Handbook for measuring birds", the following traits were measured: (1).The wing length was measured from the carpal joint to the tip of the longest primary using a ruler with zero-stop and a precision of 1mm. (2) The Kipp's distance was measured with callipers and a precision of 0,5 mm. It is the distance between the tip of the first secondary and the longest primary and is positively related to migration. It is an indicator of flight quality as well (Eck et al., 2011; Kipp, 1959). The bigger the Kipp-distance, the better the flight quality of a bird. Thus, the Kipp distance plays an important role in migratory behaviour (Kipp, 1959). (3) Tail feather length was also measured with a ruler with zero-stop and an accuracy of 1mm using either the left or the right feather of the tail from the dorsal side. (4) Bill length and (5) bill depth, (6) tarsus length and (7) hind claw length were measured with callipers and a precision of 0,5 mm. The length of the bill was measured from the anterior edge of the cere to the tip of the bill. Its depth was measured at the centre edge of the nostrils only taking the upper mandible into account because many study skins do not have completely closed mandibles. Measurement of tarsus length were taken from the intertarsal joint to the joint between hind toe and tarsus. The size of the hind claw was measured from the dorsal exit of the claw from the skin to the tip of the claw. These traits were chosen because they were found useful for such kind of eco-morphological studies and usually did not correlate with each other (A. Gamauf et al., 1998; Riesing et al., 2003).

Figure 19: Study skin (Tawny Owl), measuring equipment (ruler, callipers) and DO˙G handbook (Eck et al., 2011).

Data analyses

Pearson product-moment correlation coefficient (hereafter: PPMCC) was used to associate each morphological trait with a year and the respective temperature (Rudolf & Kuhlisch, 2008). The first data-set contains all individuals with complete data (n=996) and the second data-set includes all measured individuals with replaced missing data (n=1080). For the replacement of missing data, a multiple imputation was conducted by using MICE package. For each missing data five estimated values were provided by using predictive mean matching. Afterwards both correlation matrices were compared with each other and the correlation coefficient was equal to the second decimal place. A linear correlation, either positive or negative, between traits and year, as well as traits and temperature, would be a precondition for regression analysis (Fowler & Cohen, 1995). The first step of the analysis was to compare the complete (n=996) and the imputed (n=1080) data-set with each other. The imputed data-set with replaced values and 35 excluded specimens was used for all further analysis (Table 1). The next step was to split the data-set into 2 periods, an early period from 1880-1970 and a late period from 1970-2015. In a final step, after splitting the data-set into the 4 above-mentioned categories and using PPMCC, regression analysis was conducted when Bonferroni correction showed significant correlations between traits and year or traits and temperature (Rudolf & Kuhlisch, 2008). When significant correlations were found, LOESS (locally weighted scatterplot smoothing) curve was used. It is as non-parametric regression procedure, which estimates how strong variables are connected to each other.

Results

The complete data-set

The first step of the analysis, including all measured specimens, revealed that time has an almost small effect on wing length and tail length with r = 0.099. Also Kipp's distance is positively significant when level of significant is α = 0,05. After Bonferroni correction the significance level is α = 0,00357, which means that there is a tendency for slight increase of wing length and tail length over time. After using local regression, the Loess curve shows that the correlation is not linear and that wing length increased until about 1970 and decreased since that time (Fig. 20, 21).

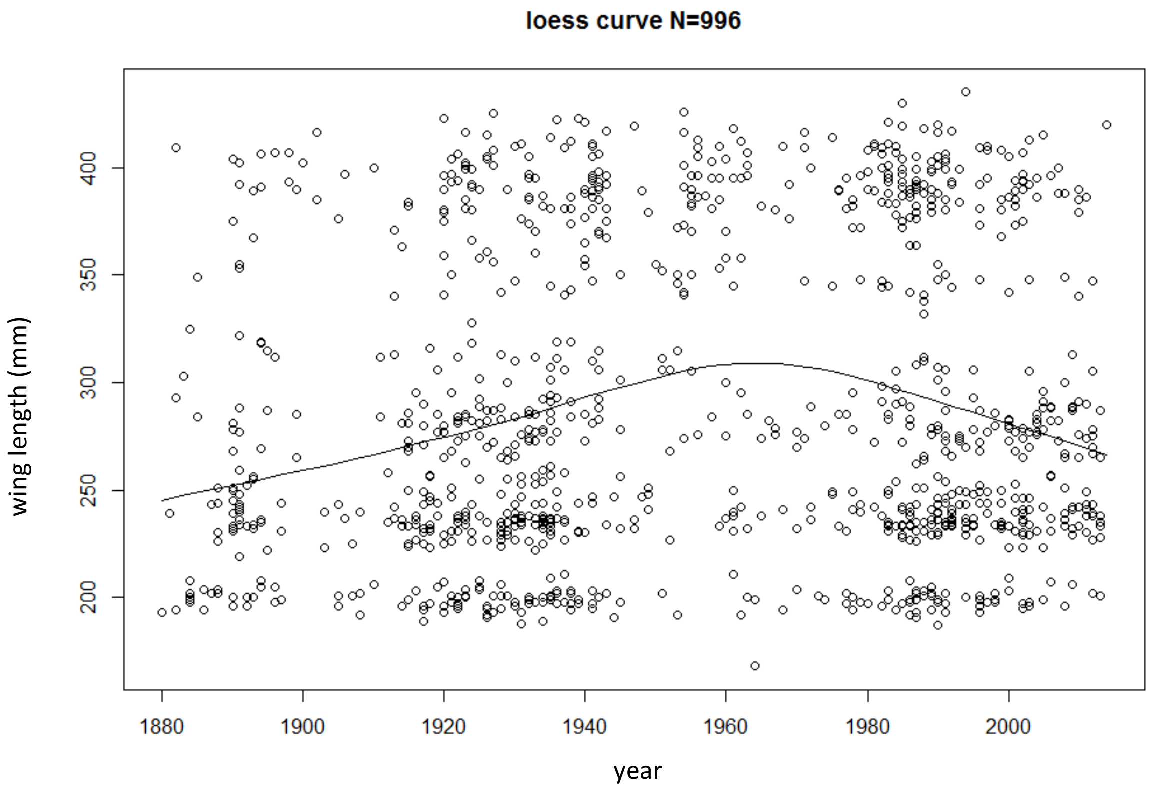

Figure 20: Loess curve results for all specimens.

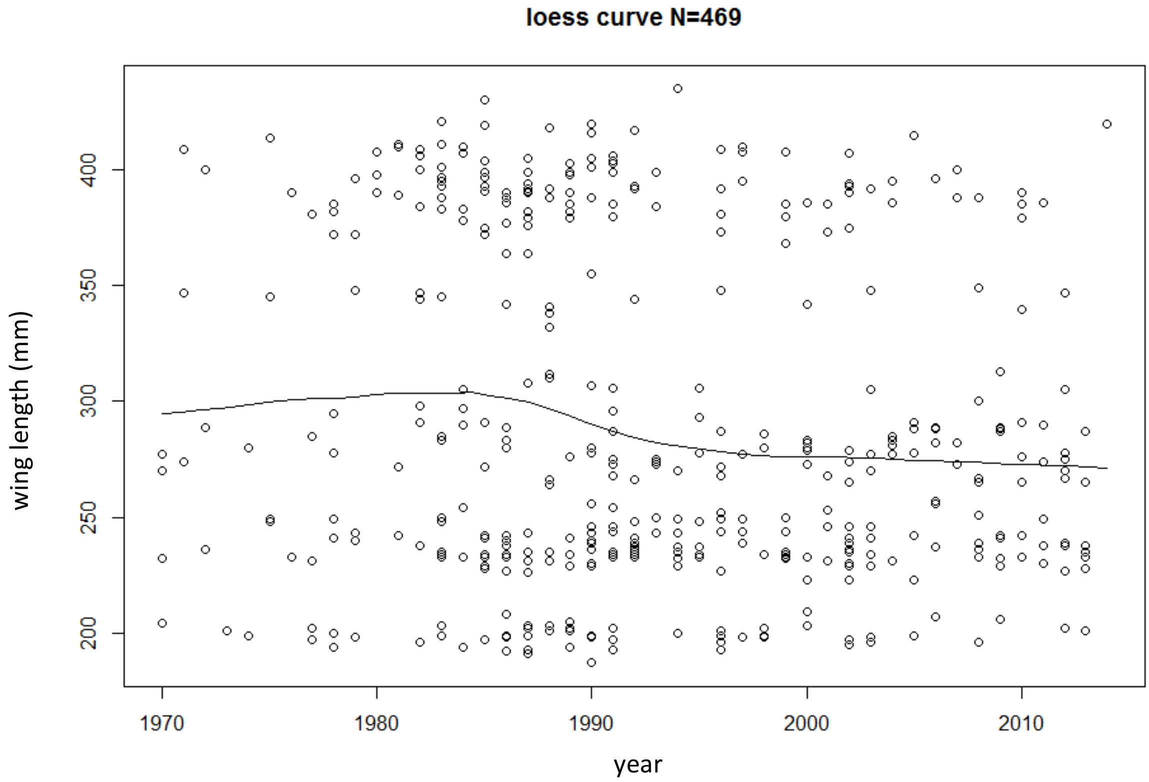

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Figure 21: Loess curve results for late period

The split data-set by species, sex and age level

After splitting data-set into an early and a late period, analysis show, that since 1970 the five investigated raptor species decreased on average when using wing length for estimating body size (wing length: r = -0.14) and increased from 1880 to about 1970 (wing length: r = 0.22). There is a significant negative correlation for the late period and a negative correlation for the early period. After using multiple regression and wing length as dependent variable, there is no longer a correlation between morphological traits and time. Hence, I couldn't definitely prove that time has a significant effect on body size or influences morphological changes, neither in the early period, nor in the late period. Appendix 6 gives an overview of correlations between morphological characteristics in all five raptor species.

The final step of analysis was splitting the complete data-set into 4 categories (male, female, adult and juvenile) and evaluating every bird species individually. None of the analysed raptor species showed significant correlations, neither between year and morphological traits nor between temperature and morphological traits.

The situation was different when every species was evaluated individually. The Northern Goshawk shows, for all 21 characters, modest and strong correlations. (Appendix 7). Adult individuals show stronger correlations between morphological traits than juveniles (Tab. 3 and Appendix 8-11).

Similar results were found for the Eurasian Sparrowhawk. It also shows for all 21 characters strong and very strong correlations. Among them weak effects on the tail feather length, temperature and year as well as the tarsus length, temperature and year were found. After Bonferroni correction those correlations were no longer significant. Because of the good Sparrowhawk data-set, more detailed analyses were possible. Analysis of juvenile females (n=121) revealed altogether 17 correlations between morphological characteristics and a significant correlation between year and tail feather length (r = 0.32) (Fig. 22). A linear model does not support the thesis of an increasing tail feather length. Juvenile males (n= 121) show only 4 correlations between morphological traits and most of them are weak. Adult Sparrowhawks, males (n= 72) as well as females (n= 93), showed strong and very strong correlations for all characteristics.

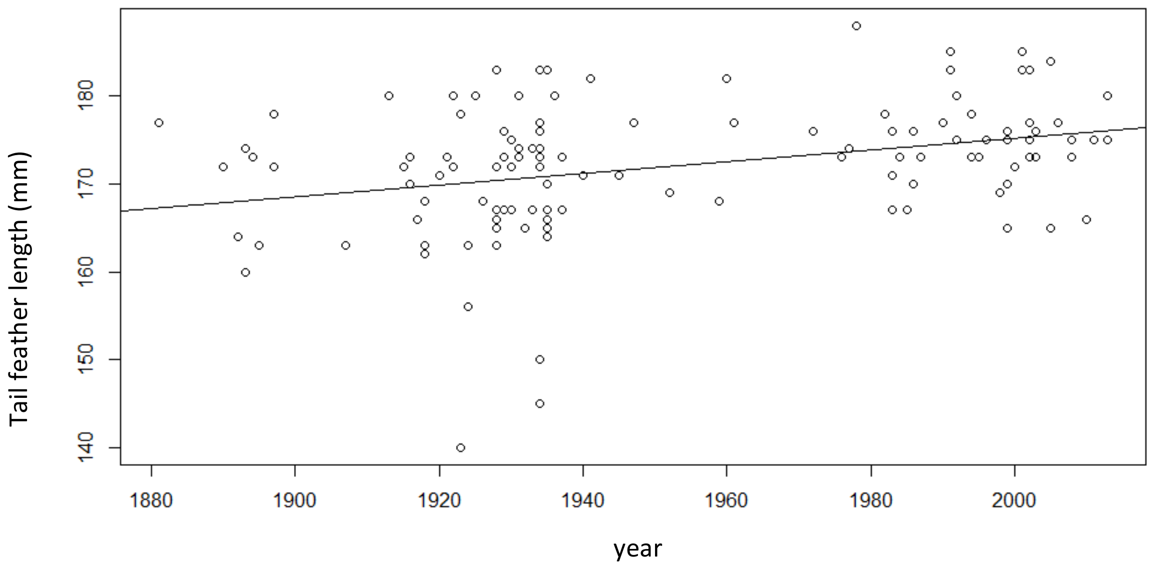

Figure 22: Correlation between tail feather length and year in juvenile female Sparrowhawks.

There is a weak correlation between year and tarsus length of Common Buzzards, when all measured individuals are considered. After using Holm–Bonferroni method the correlation is no longer significant. Females, adult (n= 72) as well as juvenile individuals (n= 67), showed 15 modest correlations between morphological traits while male individual show only 1 modest correlation in juvenile males (n= 50) and 9 modest correlations in adult males (n=69).

Considering all measured individuals of the Eurasian Kestrels, there is a significant correlation between year and wing length as well as between year and tarsus length. After Bonferroni correction the tarsus length is still significant. Altogether there are 11 correlations between morphological traits. Adult females (n= 40) show 3 correlations from weak to strong between morphological traits. Juvenile females (n= 24) show only 1 modest correlation, adult males (n= 45) 2 correlations and juvenile males (n= 12) 2 of 21 possible correlations between morphological traits.

Table 2: Number of significant correlations between morphological characters out of 21 correlations possibilities. m= male, f= female, juv= juvenile, ad= adult;

	Northern Goshawk (n=107)	Eurasian Sparrowhawk (n=379)	Common Buzzard (n=258)	Eurasian Kestrel (n=121)	Tawny Owl (n=180)
all	21 (100%)	21 (100%)	15 (71%)	11 (48%)	4 (19%)
f juv	21 (100%)	15 (71%)	14 (66%)	5 (23%)	3 (13%)
f ad	21 (100%)	21 (100%)	15 (71%)	13 (62%)	3 (13%)
m juv	21 (100%)	4 (19%)	2 (0.1%)	3 (14%)	2 (0.1%)
m ad	21(100%)	21 (100%)	11 (52%)	6 (28%)	5 (23%)

Table 3: Correlation coefficients of morphological characteristics of five aerial predators in total and differentiated into sex and age classes.
(**=p < 0.001, *=p ≤ 0.002, °=p≤ 0.05 but after Bonferroni correction no longer significant; f= female, m= male, ad= adult, juv= juvenile
Wl= wing length, Ki= Kipps's distance, Tfl= tail feather length, Bl= beak length, Bd= beak depth, Hc= hind claw length, Ta= tarsus length)

Species	Wl-Ki	Wl-Tfl	Wl-Bl	Wl-Bd	Wl-Hc	Wl-Ta	Ki-Tfl	Ki-Bl	Ki-Bd	Ki-Hc	Ki-Ta	Tfl-Bl	Tfl-Bd	Tfl-Hc	Tfl-Ta	Bl-Bd	Bl-Hc	Bl-Ta	Bd-Hc	Bd-Ta	Hc-Ta
A. gentilis all	0.74**	0.72**	0.77**	0.72**	0.76**	0.67**	0.56**	0.62**	0.63**	0.65**	0.61**	0.77**	0.72**	0.75**	0.69**	0.87**	0.81**	0.75**	0.75**	0.77**	0.73**
f ad	0.78**	0.82**	0.91**	0.78**	0.85**	0.67**	0.54°	0.76**	0.72**	0.58°	0.52°	0.80**	0.70**	0.83**	0.72**	0.86**	0.89**	0.70**	0.76**	0.71**	0.72**
f juv	0.71**	0.85**	0.79**	0.74**	0.84**	0.75**	0.50*	0.41°	0.39°	0.54**	0.55**	0.76**	0.67**	0.66**	0.69**	0.75**	0.82**	0.71**	0.70**	0.63**	0.77**
m ad	0.84**	0.76**	0.58**	0.87**	0.86**	0.77*	0.57°	0.75**	0.79**	0.79**	0.66°	0.84**	0.70**	0.79**	0.61°	0.91**	0.84**	0.75**	0.74**	0.82**	0.67°
m juv	0.58*	0.56*	0.61**	0.55°	0.53°	0.51°	0.66**	0.45°	0.59**	0.51°	0.66**	0.73**	0.75**	0.77**	0.74**	0.89**	0.65**	0.80**	0.77**	0.89**	0.72**
A. nisus all	0.95**	0.92**	0.92**	0.86**	0.90**	0.84**	0.88**	0.87**	0.81**	0.85**	0.81**	0.84**	0.80**	0.86**	0.78**	0.85**	0.88**	0.83**	0.81**	0.78**	0.82**
f ad	0.93**	0.93**	0.94**	0.85**	0.82**	0.87**	0.87**	0.86**	0.77**	0.77*	0.84**	0.88**	0.78**	0.83**	0.79**	0.84**	0.80**	0.83**	0.70**	0.78**	0.76**
f juv	0.69**	0.74**	0.36**	0.38**	0.37**	0.30**	0.55**	0.26°	0.30**	0.23°	0.28*	0.21°	0.36**	0.31**	0.18°	0.33**	0.48**	0.30**	0.33*	0.23°	0.32**
m ad	0.96**	0.95**	0.94**	0.83**	0.95**	0.85**	0.91**	0.93**	0.80**	0.91**	0.83**	0.90**	0.81**	0.93**	0.82**	0.83**	0.94**	0.83**	0.83**	0.76**	0.88**
m juv	0.73**	0.45**	0.27°	0.27°	0.33**	-0.13	0.41**	0.17	0.06	0.21	-0.09	0.13	0.17	0.20	0.01	0.29°	0.18	0.13	0.10	0.12	-0.05
B. buteo all	0.69**	0.55**	0.63**	0.47**	0.56**	0.07	0.49**	0.44**	0.34**	0.40**	0.09	0.36**	0.33**	0.32**	0.01	0.68**	0.60**	0.07	0.49**	0.08	0.14°
f ad	0.66**	0.48**	0.59**	0.50**	0.53**	-0.05	0.42**	0.41**	0.38 °	0.26°	-0.18	0.34°	0.39*	0.30°	-0.13	0.68**	0.49**	0.00	0.41**	-0.05	0.00
f juv	0.71**	0.59**	0.73**	0.68**	0.65**	0.14	0.50**	0.52**	0.56**	0.55**	0.24	0.45**	0.53**	0.49**	0.01	0.81**	0.61**	0.01	0.61**	0.13	0.04
m ad	0.73**	0.71**	0.56**	0.28°	0.50**	0.01	0.62**	0.39**	0.13	0.31**	0.10	0.35**	0.15	0.29	0.00	0.52**	0.65**	0.17	0.41**	0.07	0.11
m juv	0.11	0.57**	0.09	0.11	-0.01	-0.06	0.17	-0.11	-0.14	0.24	0.03	-0.21	-0.32	0.01	0.21	0.43°	0.26	0.12	-0.03	-0.27	0.32
F. tinnunculus all	0.79**	0.51**	0.40**	0.38**	0.42**	0.10	0.37**	0.20 °	0.18	0.34**	0.09	0.34**	0.37**	0.28°	0.22°	0.49**	0.40**	0.28°	0.28°	0.17	0.18
f ad	0.83**	0.54**	0.27	0.42°	0.40°	0.31	0.35°	0.26	0.29	0.43°	0.30	0.32°	0.39°	0.11	0.26	0.59**	0.36°	0.34°	0.37°	0.36°	0.15
f juv	0.82**'	0.33	0.48°	0.54°	0.50°	-0.19	0.24	0.13	0.43	0.37	0.05	0.22	0.43	0.33	-0.12	0.54°	0.40	-0.18	0.20	0.39	0.01
m ad	0.84**	0.53**	0.01	0.00	0.26	-0.11	0.41°	-0.19	-0.28	0.17	-0.15	0.09	0.14	0.32°	0.14	0.11	0.39°	0.30°	0.00	0.04	0.25
m juv	0.85**	0.41	0.25	0.52	0.57	-0.01	0.14	-0.08	0.40	0.22	0.09	0.29	0.41	0.82*	0.15	0.52	0.68°	0.02	0.55	-0.25	0.09
S. aluco all	0.37**	0.51**	0.21°	0.19°	0.35**	0.04	0.21°	0.09	0.00	0.02	0.04	-0.03	-0.05	0.22°	-0.01	0.32**	0.26**	0.17°	-0.16°	-0.22°	0.14
f ad	0.44°	0.57**	0.07	-0.08	0.18	0.07	0.20	0.06	-0.12	-0.19	0.01	-0.21	-0.24	0.08	-0.01	0.34°	-0.11	0.29	0.02	-0.19	0.06
f juv	0.33°	0.27	0.19	-0.23	0.24	0.06	0.09	0.25	-0.04	-0.11	-0.34°	-0.12	-0.13	0.27	-0.24	0.29°	0.16	0.09	0.06	-0.17	0.05
m ad	0.29	0.64**	0.11	0.32°	0.25	-0.02	0.24	-0.10	0.04	-0.04	0.49**	0.26	0.30	0.28	0.01	0.12	0.44°	0.14	0.19	-0.33°	0.12
m juv	0.11	0.57**	-0.09	0.11	-0.01	-0.06	0.17	-0.11	-0.14	0.24	0.03	-0.21	-0.32	0.00	0.21	0.43°	0.26	0.12	0.03	-0.27	0.32

Discussion

Many studies have investigated the influence of climate change especially, on birds and mammals (Millien et al., 2006; Root et al., 2003; Scheifinger et al., 2005; Walther et al., 2002). Some authors claim that morphological changes and decline in body size could be one of many responses to global warming (Berthold, 1998; Gardner et al., 2014; Jakober & Stauber, 2000; Millien et al., 2006; Salewski et al., 2014; Sheridan & Bickford, 2011; Smith & Betancourt, 2006). The present study does not support the hypothesis of changing body size in aerial predators due do time or temperature over the last 135- year period. The results show neither significant correlations between year and morphological characteristics nor significant correlations between temperature and morphological traits. While some researchers determine that decrease in body size is influenced by global warming, others cannot find definite proof for that hypothesis (Gardner et al., 2014; Reside et al., 2015; Salewski et al., 2014; Sheridan & Bickford, 2011; Teplitsky & Millien, 2014; Van Buskirk et al., 2010; Yom-Tov & Yom-Tov, 2006; Yom-Tov et al., 2006)

Furthermore, the different authors disagree in the choice of the morphological characters. In some of those studies wing length was used as a surrogate for body size, which may easily falsify results (Freeman & Jackson, 1990; Senar & Pascual, 1997). Changes in wing length can have several reasons. They are not necessarily connected to global warming, but may be caused by migratory behaviour (Fiedler, 2003; Förschler & Bairlein, 2011). As a consequence of global warming, winters are milder and migratory species do not have to migrate as far as in the past. Therefore, shorter wings may indicate shorter flight distance and lower migration activity (Fiedler, 2003; Förschler & Bairlein, 2011). Decreasing wing length within a species may be an indirect adaptation to global warming. But this should not be interpreted as general decrease of body size due to climate change. Hogstad (2011) claimed that for passerine species wing length is the best predictor. Also Gosler et al. (2010) claim that wing length has the best repeatability in passerines and should be taken when possible. Furthermore, Gosler et al. (2010) assess that wing length and tarsus length are the best size measure for nestlings, although its not proven if the same applies for adult individuals or other bird groups as well.
Contrary to that, Freeman & Jackson (1990) claim that tarsus length and mass are the best surrogates for overall body size, but combining several measurements may also lead to biased and contradictory results. Also the investigations of Rising & Somers (1989) produce the result,

that wing length is a poor predictor for body size and weight should be taken instead to get the best indication of overall body size. But as body weight of a bird individual can vary within one year drastically (in birds of prey up to 30%), collecting only this data may also lead to falsified results (Glutz von Blotzheim & Bauer, 1980; Glutz von Blotzheim et al., 1989).
But it has to be recorded that all these studies have been conducted with living animals and not with museum specimens. Therefore, the results must not necessarily be in accordance. Additionally, only one or two characters are maybe not enough for size categorisation.

Evolutionary adaptations, such as changes in body size and other morphological characteristics require time. In contrast to e.g. genetic adaptations to environmental conditions, morphology can adapt in a relatively short time (Grant & Grant 1982). Furthermore, adaptations within generations are faster in short-living species (e.g. many songbirds) in comparison to long-living species, such as birds of prey (Grant & Grant, 1982). Some authors think is improbable that such changes can be seen within a few decades (Teplitsky & Millien, 2014), but in small bird species like Galapagos finches such changes were found within a few generations (Grant & Grant 1982). So far, only few studies could show evidance changes in morphological characteristics (Berthold, 1998; Berthold, Helbig, Mohr, & Querner, 1992; Boag & Grant, 1981; Fleischer & Johnston, 1982; Grant & Grant, 1982).

Evolutionary adaptations, such as changes in body size and other morphological characteristics require time. In opposite to e.g. genetic adaptations to environmental conditions, morphology can adapt in relatively short time. Besides, adaptations within generations are faster in short-living species (e.g. many songbirds) in comparison to long-living species, such as birds of prey. (Grant & Grant, 1982). Some authors think is improbable that such changes can be seen within few decades. (Teplitsky & Millien, 2014).
So far, only few studies could evidence changes of morphological characteristics (Berthold, 1998; Berthold, Helbig, Mohr, & Querner, 1992; Boag & Grant, 1981; Fleischer & Johnston, 1982; Grant & Grant, 1982).

The results presented here are in contrast to others that found proof of changes of body size in birds (Gardner et al., 2014; Tornberg, Mönkkönen, & Pahkala, 1999; Yom-Tov & Yom-Tov, 2006; Yom-Tov et al., 2006) [but compare (Moreno-Rueda & Rivas, 2007; Salewski et al., 2014)]. Another hypothesis for changes of morphological characteristics is connected to food preferences. Due to their morphological traits, the five investigated species can be divided into specialists and generalists. Fortunately, from the study area there are many diet related data for all five raptor species available (Tab. 4). In Fig. 23 the result for the calculated Levin's index for each species is shown. The smaller this index, the more specialized the raptor species is on one kind of prey category (MacArthur & Levin, 1964). The higher the specification, the higher the number of correlations between morphological characteristics (Tab. 4 & Fig 23). The Goshawk and the Sparrowhawk are specialised on birds and show the strongest correlations among morphological characteristics. Although Yom-Tov and Yom-Tov (2006) claim that Danish Goshawks decreased in size since the 1980's, the evaluation of the present thesis shows different results. It cannot be said whether the differences between the two studies are based on the different methods or geographic region.

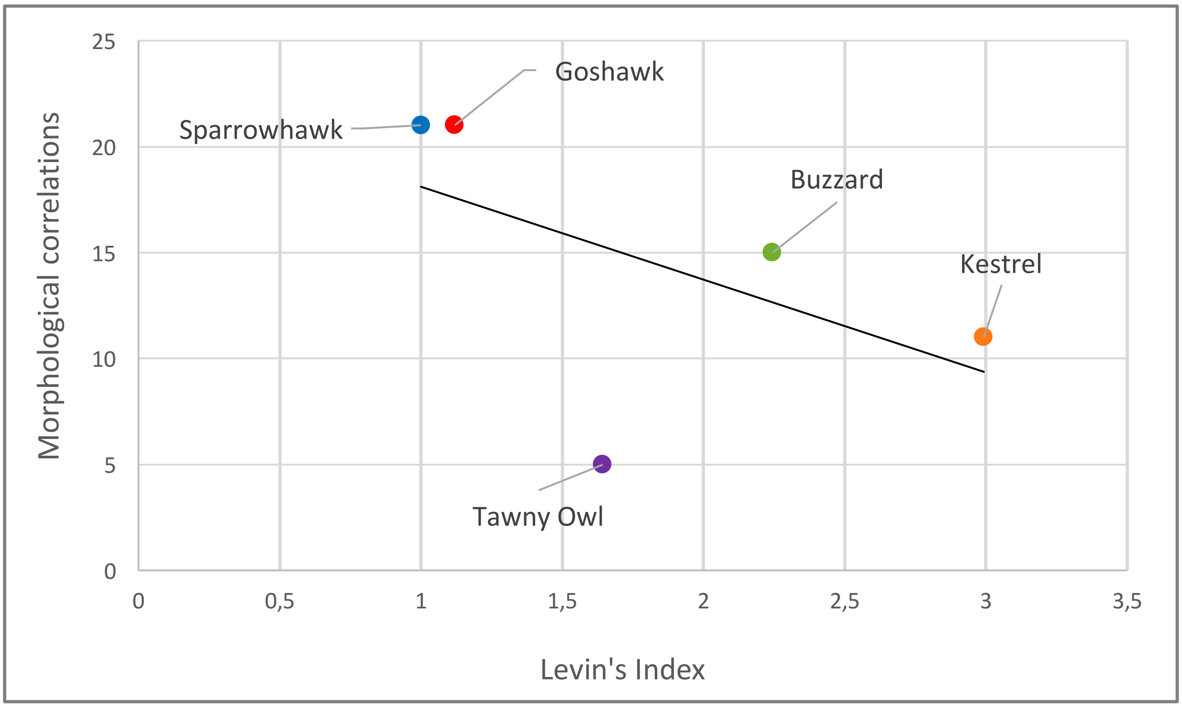

Figure 23: Levin's index for the 5 examined species. Sparrowhawk: 1; Goshawk: 1,12; Tawny Owl: 1,64; Buzzard: 2,24; Kestrel: 2,99 (Gorgon, 2015 nach Deschka, 2002; A. Gamauf, 1991; Steiner, 1961; Sumasgutner P., Krenn H.W., Düesberg D., Gaspar T., & Gamauf, 2013)

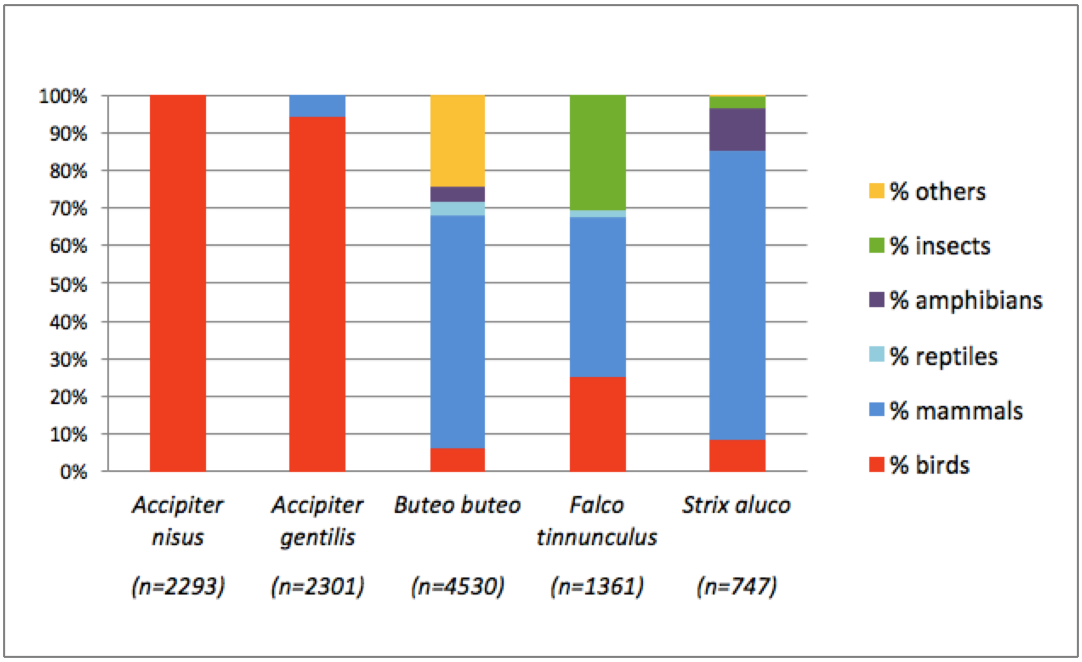

Table 4: Diet composition of the 5 examined species (Deschka, 2002; A. Gamauf, 1991; Steiner, 1961; Sumasgutner P., Krenn H.W., Düesberg D., Gaspar T., & Gamauf, 2013)

Both the Northern Goshawk, as well as the Eurasian Sparrowhawk, show for all 21 morphological characteristics significant correlations for adult specimens. The same is true for juvenile Goshawks, but juvenile females show stronger correlations compared to juvenile males. The same was observed in juvenile Sparrowhawks. While juvenile females show 17 strong correlations, juvenile males display only 4 significant correlations. However, adult and juvenile female Common Buzzards show 15 correlations while adult males only 9. The Kestrel and the Tawny Owl use the greatest prey variability, they show only between 1 and 5 correlations. This phenomenon is interpreted in the way that the higher the specification for hunting fast and agile prey species (birds), the higher the number of significant morphological correlations. On the opposite, generalist vs. opportunistic species, which are not specialised on one kind of prey category show less correlations among morphological characteristics. Although they prey in years with abundant voles (peak every 3-4 years in Central Europe) mostly on them, they are able to switch to other kind of prey when voles are scarce.

Many authors describe an interconnection between birds and their diet, especially in aerial predators and their prey (Jakober & Stauber, 2000; Pererva & Grazhdankin, 1994; Tornberg et al., 1999). Changes in prey availability, such as transition from large to small prey, may cause in morphological adaptations. Differing food availability during molt and new hunting methods could cause changes of wing length and pointedness (Jakober & Stauber, 2000). The same is true for bill shape (Grant & Grant, 1982). A strong correlation between tail and wing is obligatory for best flight performance and therefore changes particularly occur in wings and tails. (see Tab.3) (Tornberg et al., 1999). Several studies show, that in the past the Goshawk developed shorter wings and a longer tail in order to optimize its energy expenditure and to be more agile when chasing small prey in flight (Pererva & Grazhdankin, 1994; Tornberg et al., 1999; Yom-Tov & Yom-Tov, 2006).

Global warming and food availability are only two possible reasons for changes in morphology. Aerial predators are long-living animals, which may respond slower to global warming than other, especially small birds with faster alteration of generations. Additionally, it cannot be excluded that the examined period may be too short to find signs of microevolution in the five study species yet. Further, effects of global warming do not appear in the same way in all species, just as populations of the same species occurring in different habitats may react differently to climate change.

Unlike small songbirds, the predators investigated in the present thesis are much rarer available in scientific collections. This made it harder to get a good sample size for such a small study area. But a statistically significant data-set for every species, sex and age class over a defined climatological homogenous area was necessary to answer the hypotheses. Although the subdivision of each species further diminished the sample sizes, statistical methods allowed interesting eco-morphological predictions

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Appendix

Appendix 1: Shown are the mean values, standard deviation as well as maximum and minimum of the morphological characteristics of the Northern Goshawk. (fem= female, ad= adult, juv= juvenile)

Species	Morphological trait	Mean (mm)	Standard deviation (mm)	Min (mm)	Max (mm)
Goshawk all (n=107)	Wing length	328.7	18.2	247.0	367.0
	Kipp	117.3	7.6	98.0	140.0
	Tail feather length	231.9	15.3	199.0	262.0
	Bill length	24.0	1.5	19.3	26.3
	Bill depth	13.8	0.8	10.8	16.4
	Hind claw length	29.3	1.9	24.6	36.7
	Tarsus length	68.4	3.7	60.7	79.3
Fem ad (n=28)	Wing length	337.5	19.7	300.0	367.5
	Kipp	122.5	7.4	106.0	138.0
	Tail feather length	232.8	16.5	200.0	260.0
	Bill length	23.3	1.9	19.3	26.2
	Bill depth	14.0	1.2	10.8	16.3
	Hind claw length	29.8	2.2	25.9	34.2
	Tarsus length	68.9	4.6	61.9	78.5
Fem juv (n=26)	Wing length	324.0	20.9	291.0	361.0
	Kipp	113.7	7.4	98.0	128.0
	Tail feather length	227.7	14.4	207.0	257.0
	Bill length	22.6	1.6	20.0	26.2
	Bill depth	13.4	0.9	11.9	15.8
	Hind claw length	28.5	2.5	25.0	33.5
	Tarsus length	68.5	4.1	62.0	77.4
Male ad (n=28)	Wing length	336.8	22.6	301.0	366.0
	Kipp	123.8	9.2	110.0	140.0
	Tail feather length	235.8	17.1	209.0	262.0
	Bill length	24.0	2.2	19.7	26.3
	Bill depth	14.2	1.3	12.2	16.4
	Hind claw length	30.7	3.5	24.8	36.7
	Tarsus length	70.7	5.3	63.0	79.3
Male juv (n=39)	Wing length	321.6	26.5	247.0	365.0
	Kipp	113.6	8.1	101.0	133.0
	Tail feather length	233.8	17.9	199.0	260.0
	Bill length	22.7	1.9	19.8	26.1
	Bill depth	13.7	1.1	12.0	15.7
	Hind claw length	28.7	2.6	24.6	34.4
	Tarsus length	67.5	4.4	60.7	75.6

Appendix 2: Shown are the mean values, standard deviation as well as maximum and minimum of the morphological characteristics of the Eurasian Sparrowhawk. (fem= female, ad= adult, juv= juvenile)

Species	**Morphological trait**	**Mean (mm)**	**Standard deviation (mm)**	**Min (mm)**	**Max (mm)**
Sparrowhawk all (n=379)	Wing length	218.7	18.2	168.0	250.0
	Kipp	79.0	7.6	49.2	93.1
	Tail feather length	159.3	15.3	108.0	194.0
	Bill length	12.53	1.5	9.4	15.1
	Bill depth	7.8	0.8	6.0	9.2
	Hind claw length	14.4	1.9	7.6	17.8
	Tarsus length	54.2	3.7	43.3	60.3
Fem ad (n=93)	Wing length	219.2	18.3	188.0	246.0
	Kipp	79.3	7.5	58.6	90.0
	Tail feather length	158.7	14.8	130.0	183.0
	Bill length	12.6	1.5	10.1	14.9
	Bill depth	7.9	0.9	6.1	9.2
	Hind claw length	14.4	1.9	7.6	17.3
	Tarsus length	54.15	3.6	46.1	60.3
Fem juv (n=121)	Wing length	233.2	6.4	200.0	249.0
	Kipp	84.7	3.7	62.0	93.1
	Tail feather length	172.0	7.5	140.0	188.0
	Bill length	13.66	0.6	10.8	15.1
	Bill depth	8.4	0.4	6.5	9.2
	Hind claw length	16.0	0.7	12.0	17.8
	Tarsus length	57.1	1.6	49.9	60.1
Male ad (n=72)	Wing length	219.3	18.1	189.0	250.0
	Kipp	79.4	7.0	67.3	90.3
	Tail feather length	157.5	14.5	130.0	183.0
	Bill length	12.5	1.4	10.1	14.6
	Bill depth	7.9	0.7	6.6	9.2
	Hind claw length	14.4	1.8	11.1	16.9
	Tarsus length	53.7	3.5	44.7	60.0
Male juv (n=93)	Wing length	198.5	6.0	168.0	219.0
	Kipp	70.7	3.2	49.2	78.6
	Tail feather length	144.6	8.9	108.0	194.0
	Bill length	11.0	0.6	9.4	12.6
	Bill depth	7.0	0.4	6.0	7.9
	Hind claw length	12.4	0.7	10.4	15.0
	Tarsus length	50.5	2.2	43.3	55.7

Appendix 3: Shown are the mean values, standard deviation as well as maximum and minimum of the morphological characteristics of the Common Buzzard. (fem= female, ad= adult, juv= juvenile)

Species	Morphological trait	Mean (mm)	Standard deviation (mm)	Min (mm)	Max (mm)
Buzzard all (n=258)	Wing length	394.2	13.9	350.0	435.0
	Kipp	149.1	6.5	132.3	175.2
	Tail feather length	207.5	10.6	180.0	238.0
	Bill length	22.2	1.3	19.0	25.2
	Bill depth	12.3	0.7	10.2	14.0
	Hind claw length	22.9	1.4	18.4	26.6
	Tarsus length	69.1	2.9	59.7	76.8
Fem ad (n=72)	Wing length	389.1	13.4	373.0	426.0
	Kipp	149.2	6.2	137.2	166.7
	Tail feather length	204.3	10.4	180.0	225.0
	Bill length	22.3	1.3	19.6	25.2
	Bill depth	12.3	0.7	10.8	14.0
	Hind claw length	22.9	1.2	20.0	25.4
	Tarsus length	69.2	2.8	64.3	76.3
Fem juv (n=67)	Wing length	391.3	12.9	364.0	423.0
	Kipp	148.8	5.8	134.6	164.0
	Tail feather length	209.1	9.9	183.0	238.0
	Bill length	22.2	1.4	20.1	24.7
	Bill depth	12.3	0.8	10.2	14.0
	Hind claw length	23.0	1.3	19.6	26.0
	Tarsus length	68.8	2.8	59.7	74.2
Male ad (n=69)	Wing length	391.4	13.5	350.0	430.0
	Kipp	149.6	6.9	132.3	175.2
	Tail feather length	210.7	10.9	189.0	237.0
	Bill length	21.9	1.23	19.0	24.8
	Bill depth	12.2	0.6	11.2	13.8
	Hind claw length	22.6	1.4	18.4	25.2
	Tarsus length	69.0	3.0	63.0	76.6
Male juv (n=50)	Wing length	274.2	15.7	255.0	295.0
	Kipp	82.7	7.5	75.2	87.7
	Tail feather length	168.0	10.5	159.0	185.0
	Bill length	28.6	1.4	25.1	31.4
	Bill depth	10.7	0.6	9.3	13.0
	Hind claw length	15.6	1.6	14.0	17.9
	Tarsus length	42.7	2.9	39.2	53.3

Appendix 4: Shown are the mean values, standard deviation as well as maximum and minimum of the morphological characteristics of the Eurasian Kestrel. (fem= female, ad= adult, juv= juvenile)

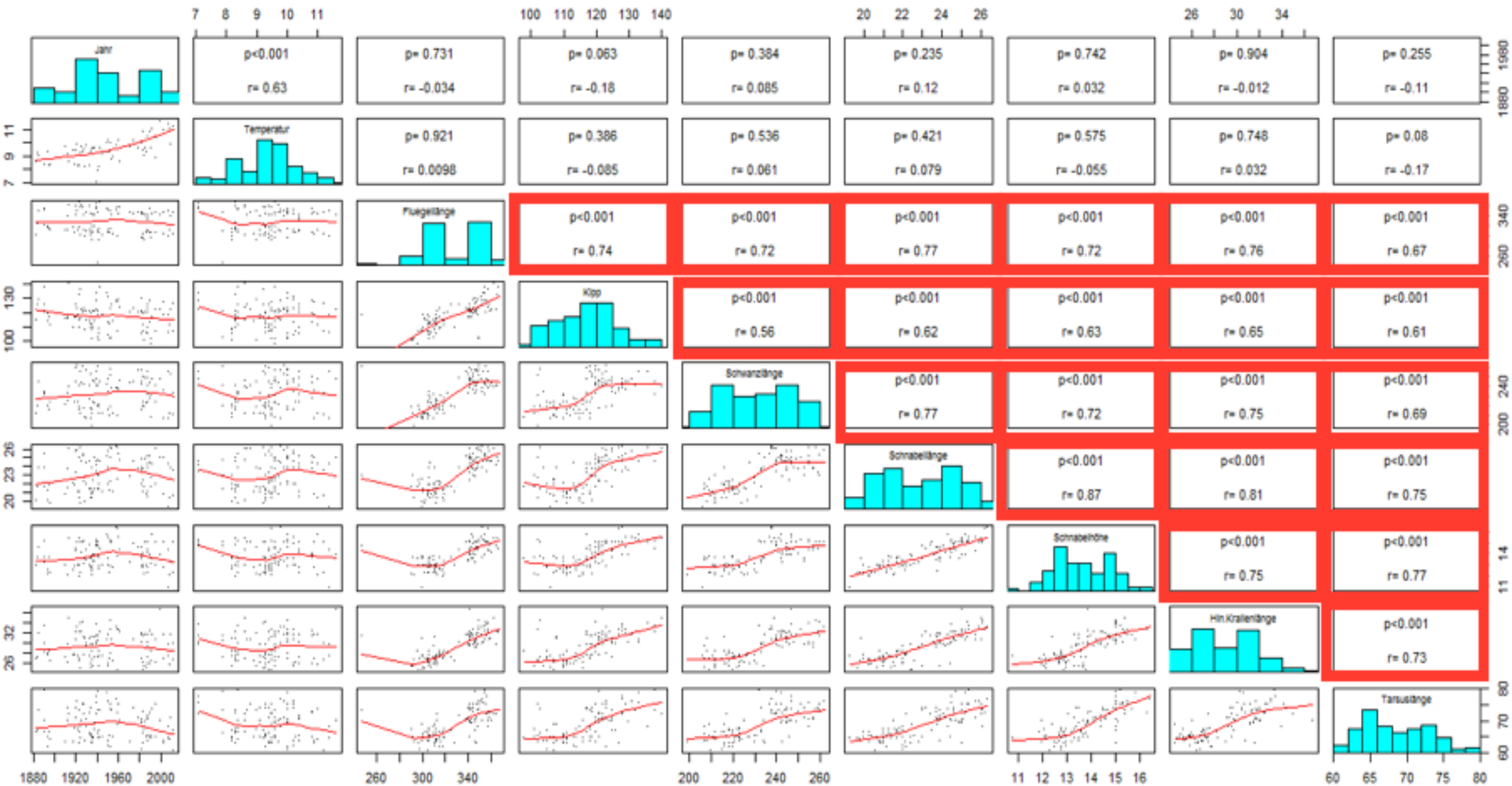
Species	Morphological trait	Mean (mm)	Standard deviation (mm)	Min (mm)	Max (mm)
Kestrel all (n=121)	Wing length	245.5	8.6	223.0	271.0
	Kipp	122.1	5.0	104.7	133.4
	Tail feather length	157.2	7.5	133.0	177.0
	Bill length	13.88	80.8	11.7	16.5
	Bill depth	8.3	0.5	6.5	9.7
	Hind claw length	11.3	0.7	9.4	13.2
	Tarsus length	38.4	2.0	31.3	41.8
Fem ad (n=40)	Wing length	250.0	8.0	233.0	271.0
	Kipp	124.0	4.6	114.3	133.4
	Tail feather length	161.0	6.2	146.0	177.0
	Bill length	14.4	0.8	12.7	16.5
	Bill depth	8.5	0.6	7.0	9.7
	Hind claw length	11.6	0.8	9.4	13.2
	Tarsus length	38.9	2.2	31.3	41.7
Fem juv (n=24)	Wing length	243.5	9.3	229.0	258.0
	Kipp	120.0	6.1	104.7	128.9
	Tail feather length	155.0	9.4	133.0	175.0
	Bill length	13.6	0.6	12.9	14.8
	Bill depth	8.2	0.5	7.0	9.0
	Hind claw length	11.0	0.7	10.1	12.5
	Tarsus length	37.5	2.1	33.8	41.3
Male ad (n=45)	Wing length	239.5	7.4	223.0	258.0
	Kipp	119.1	4.5	110.9	132.7
	Tail feather length	155.3	6.7	142.0	170.0
	Bill length	13.4	0.6	11.7	14.9
	Bill depth	8.2	0.5	6.5	9.0
	Hind claw length	11.0	0.6	9.9	12.7
	Tarsus length	38.5	2.1	33.0	41.8
Male juv (n=12)	Wing length	242.8	7.5	229.0	250.0
	Kipp	122.1	5.8	111.3	126.5
	Tail feather length	155.7	5.8	145.0	165.0
	Bill length	13.5	0.6	13.0	14.8
	Bill depth	8.2	0.4	7.4	9.0
	Hind claw length	11.2	0.5	10.3	11.9
	Tarsus length	38.2	1.8	35.2	41.3

Appendix 5: Shown are the mean values, standard deviation as well as maximum and minimum of the morphological characteristics of the Tawny Owl. (fem= female, ad= adult, juv= juvenile)

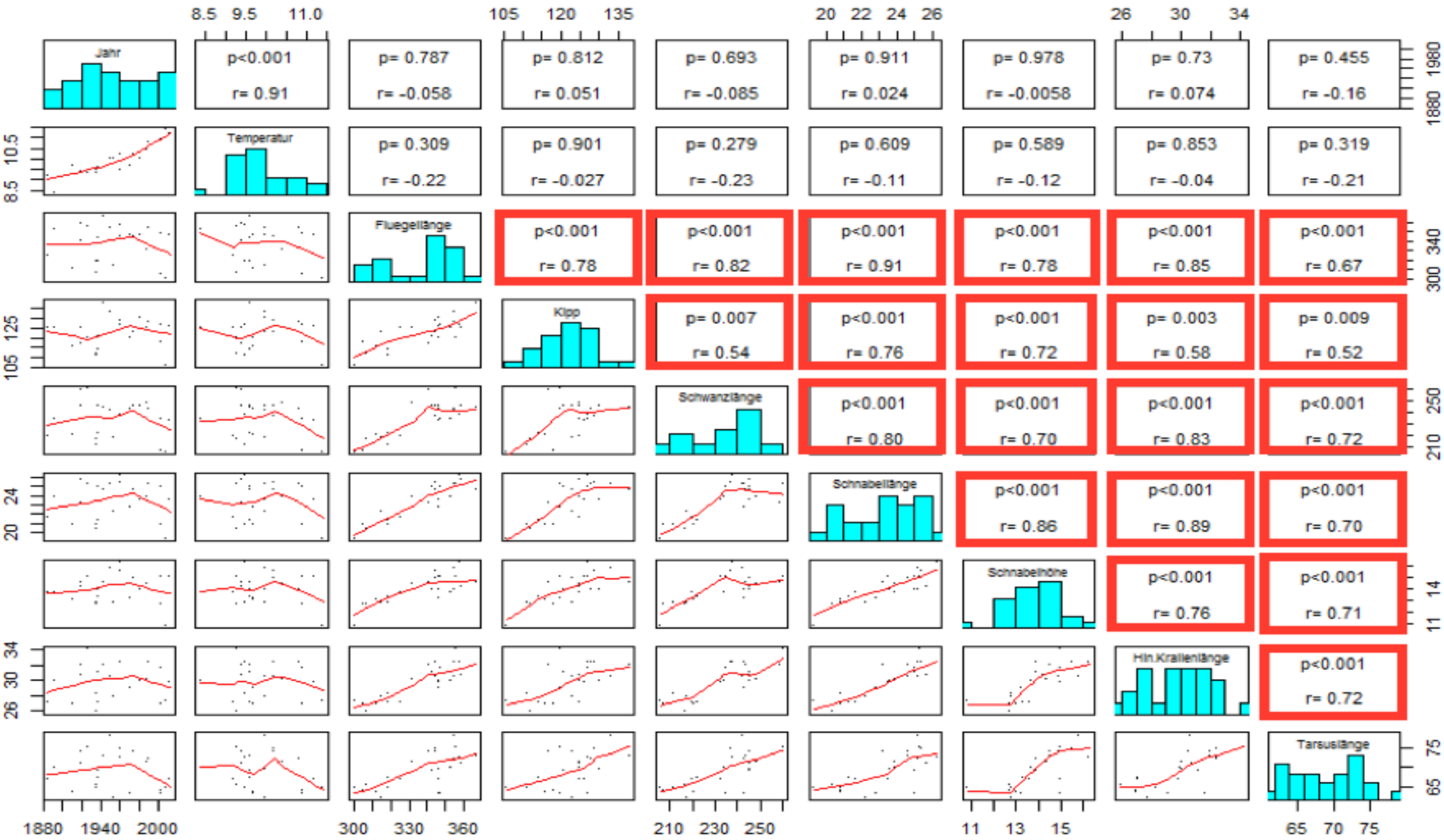
Species	**Morphological trait**	**Mean (mm)**	**Standard deviation (mm)**	**Min (mm)**	**Max (mm)**
Tawny Owl all (n=180)	Wing length	279.0	8.4	254.0	296.0
	Kipp	83.4	3.0	75.2	100.0
	Tail feather length	169.2	8.1	128.0	185.0
	Bill length	29.0	1.4	25.1	33.0
	Bill depth	10.8	0.6	9.	13.0
	Hind claw length	15.9	0.9	13.5	18.5
	Tarsus length	42.6	2.3	39.0	53.3
Fem ad (n=42)	Wing length	283.7	6.9	265.0	295.0
	Kipp	84.2	3.8	78.5	100.0
	Tail feather length	170.5	11.1	128.0	184.0
	Bill length	29.1	1.4	26.0	31.4
	Bill depth	11.0	0.7	9.1	12.4
	Hind claw length	16.1	0.9	13.5	18.5
	Tarsus length	42.2	1.9	39.0	46.5
Fem juv (n=58)	Wing length	283.0	6.2	267.0	296.0
	Kipp	83.8	2.7	76.0	89.5
	Tail feather length	171.0	7.1	152.0	185.0
	Bill length	29.5	1.4	25.6	33.0
	Bill depth	11.0	0.5	10.0	12.1
	Hind claw length	16.4	0.8	14.4	17.7
	Tarsus length	43.1	2.5	39.5	50.7
Male ad (n=41)	Wing length	274.2	7.2	255.0	295.0
	Kipp	82.7	2.7	75.2	87.7
	Tail feather length	168.0	5.7	159.0	185.0
	Bill length	28.6	1.5	25.1	31.4
	Bill depth	10.7	0.7	9.3	13.0
	Hind claw length	15.6	0.9	14.0	17.9
	Tarsus length	42.7	3.0	39.2	53.3
Male juv (n=39)	Wing length	272.6	7.3	254.0	285.0
	Kipp	82.6	2.7	75.5	88.9
	Tail feather length	166.5	7.5	150.0	182.0
	Bill length	28.6	1.3	25.4	31.0
	Bill depth	10.6	0.5	9.0	11.4
	Hind claw length	15.5	0.8	13.6	17.0
	Tarsus length	42.2	1.7	39.4	45.6

Appendix 6: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in all examined species. Significant values are marked red.

Appendix 7: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European Goshawks. Significant values are marked red.



Appendix 8: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European adult female Goshawks. Significant values are marked red.

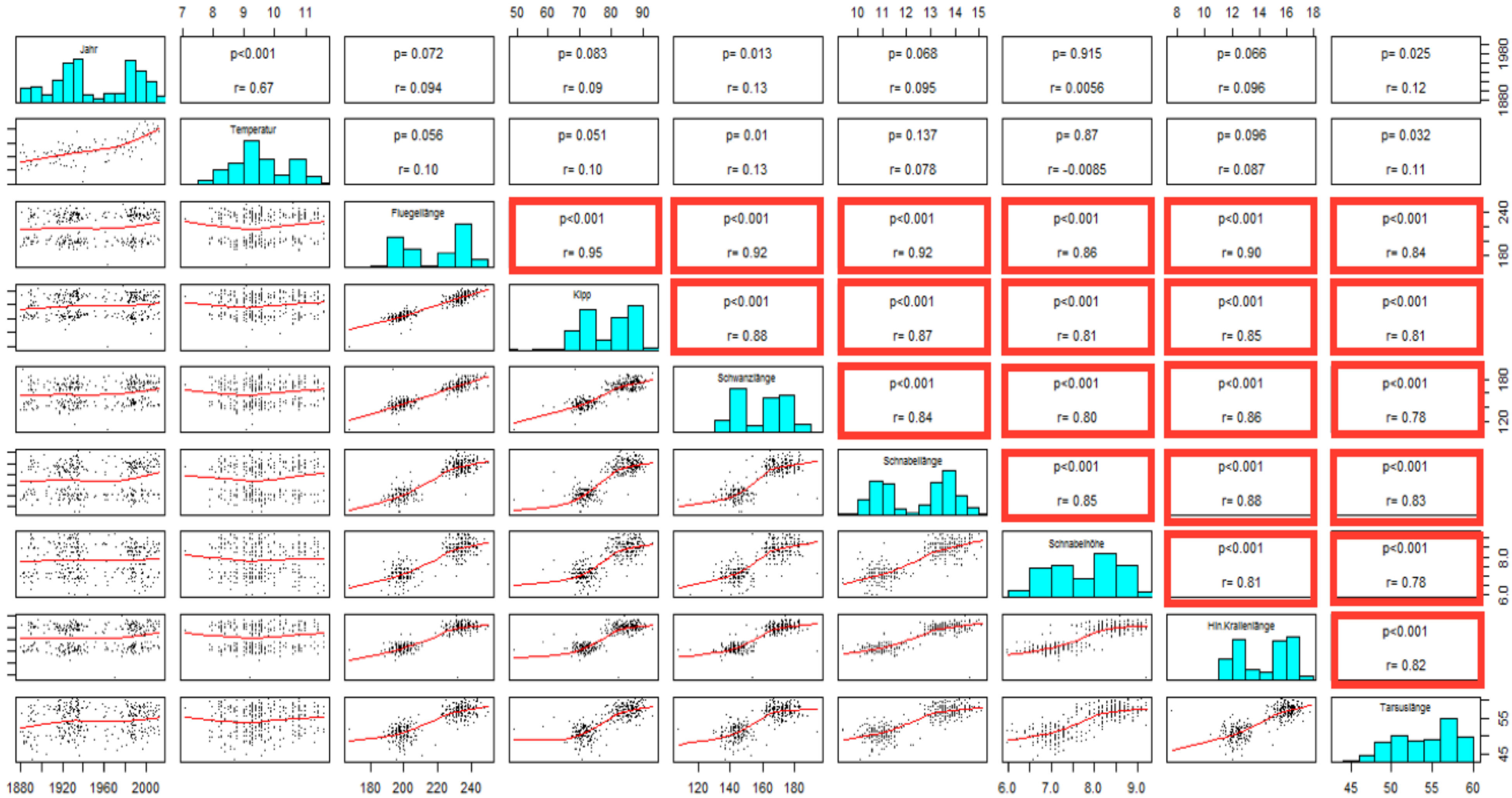


Appendix 9: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European juvenile female Goshawks. Significant values are marked red.

Appendix 10: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European adult male Goshawks. Significant values are marked red.

Appendix 11: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European juvenile male Goshawks. Significant values are marked red.

Appendix 12: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European Sparrowhawks. Significant values are marked red.

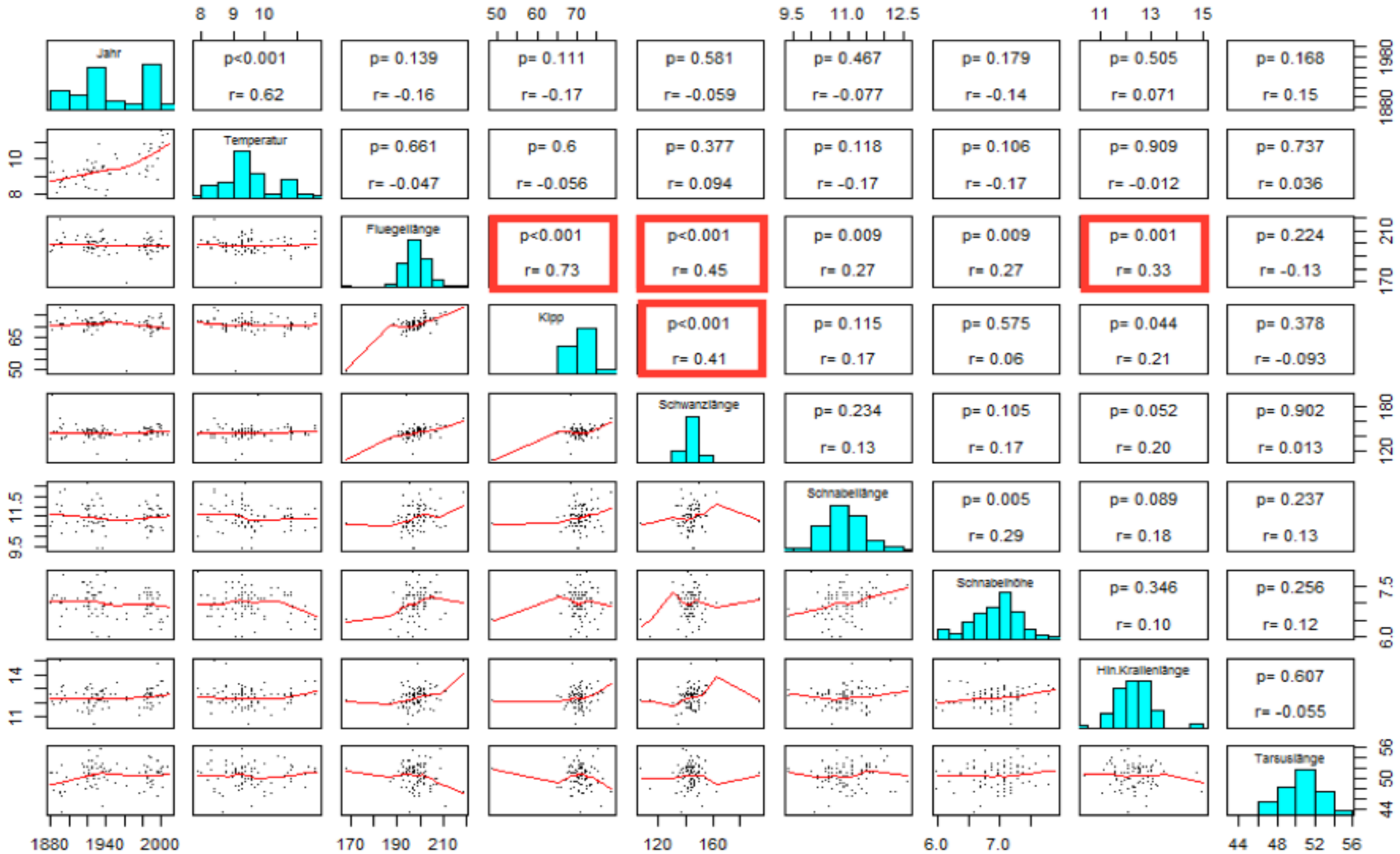


Appendix 13: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European adult female Sparrowhawks. Significant values are marked red.

Appendix 14: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European juvenile female Sparrowhawks. Significant values are marked red.

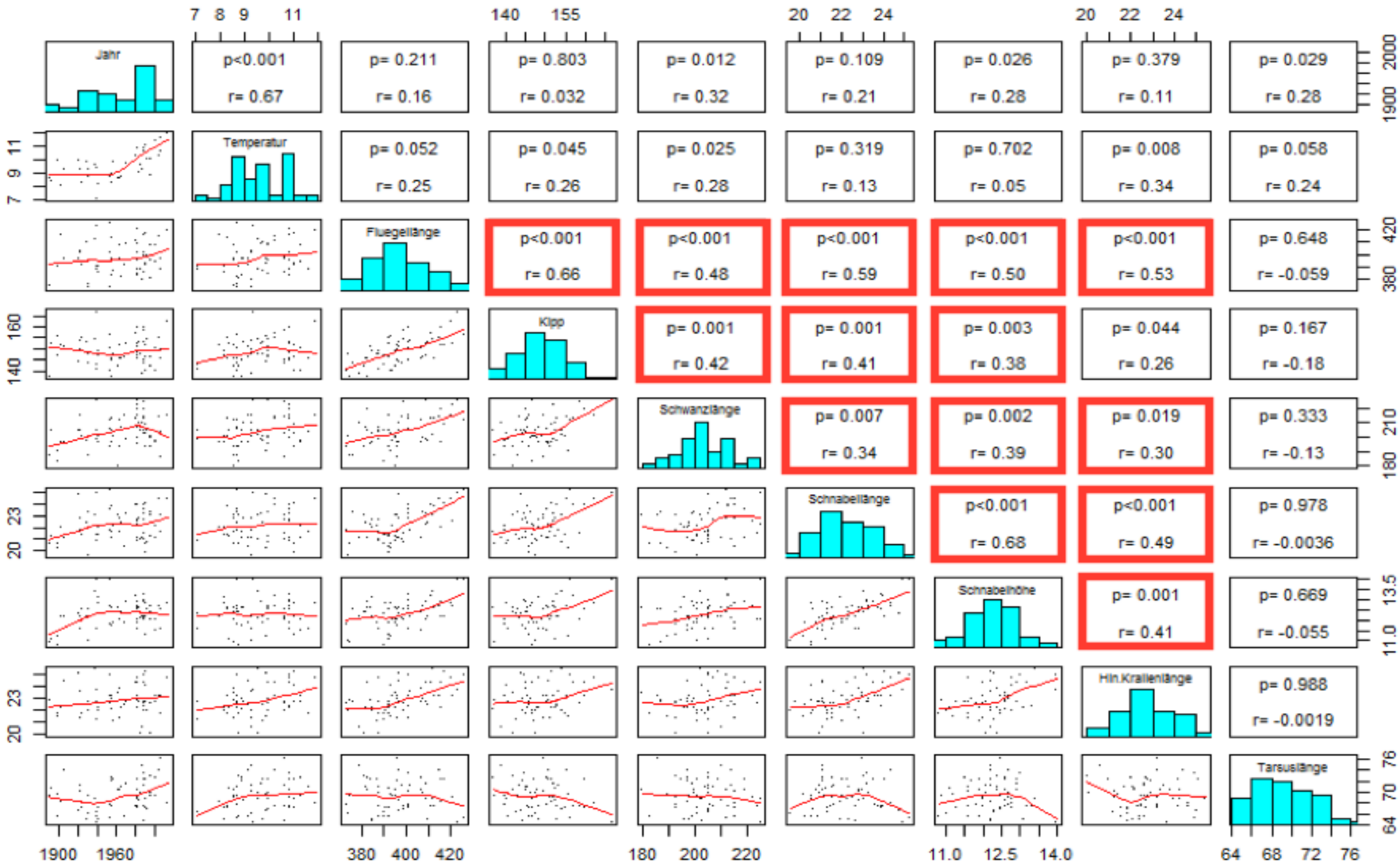
Appendix 15: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European adult male Sparrowhawks. Significant values are marked red.

Appendix 16: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European juvenile male Sparrowhawks. Significant values are marked red.

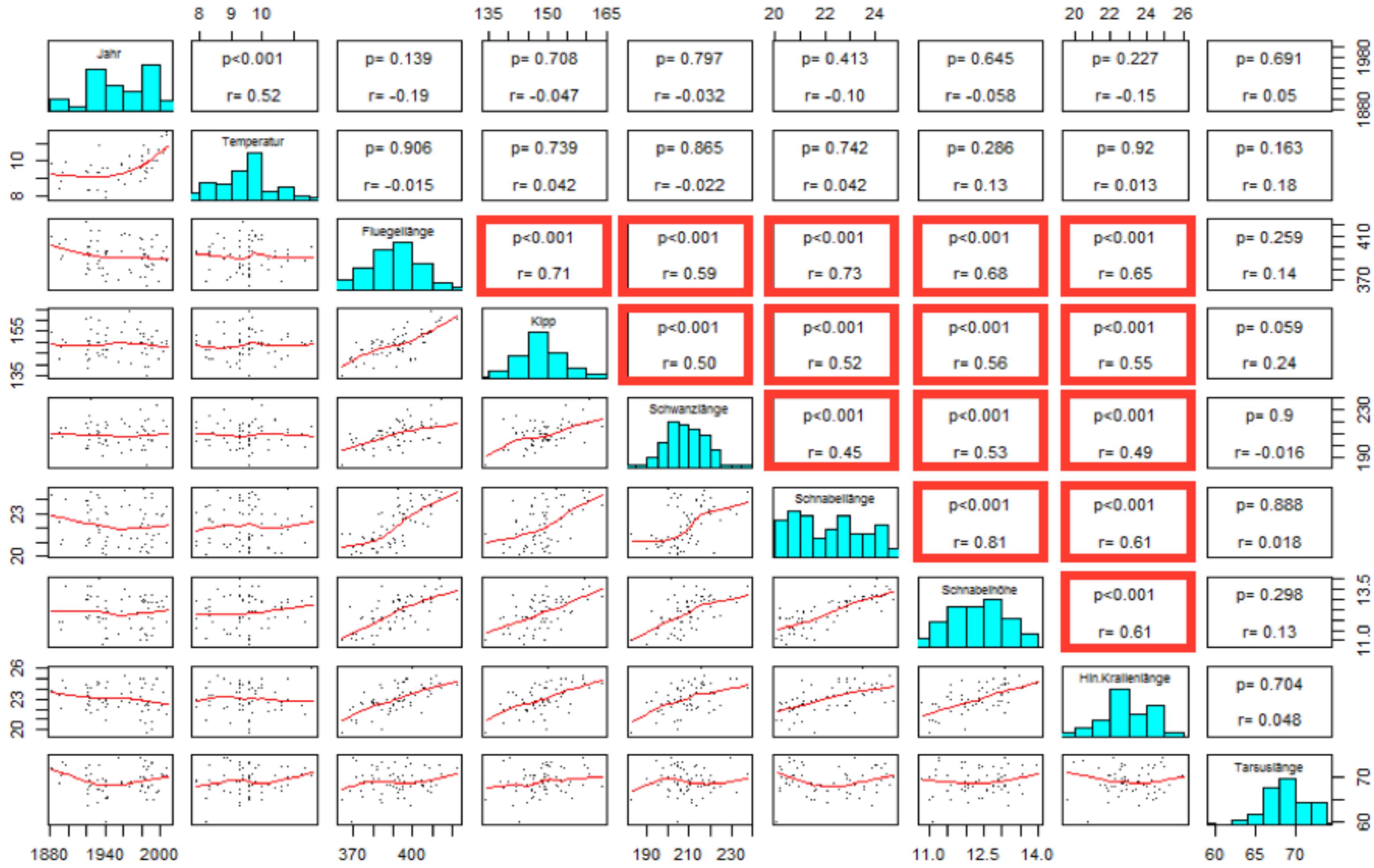


Appendix 17: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European Buzzards. Significant values are marked red.

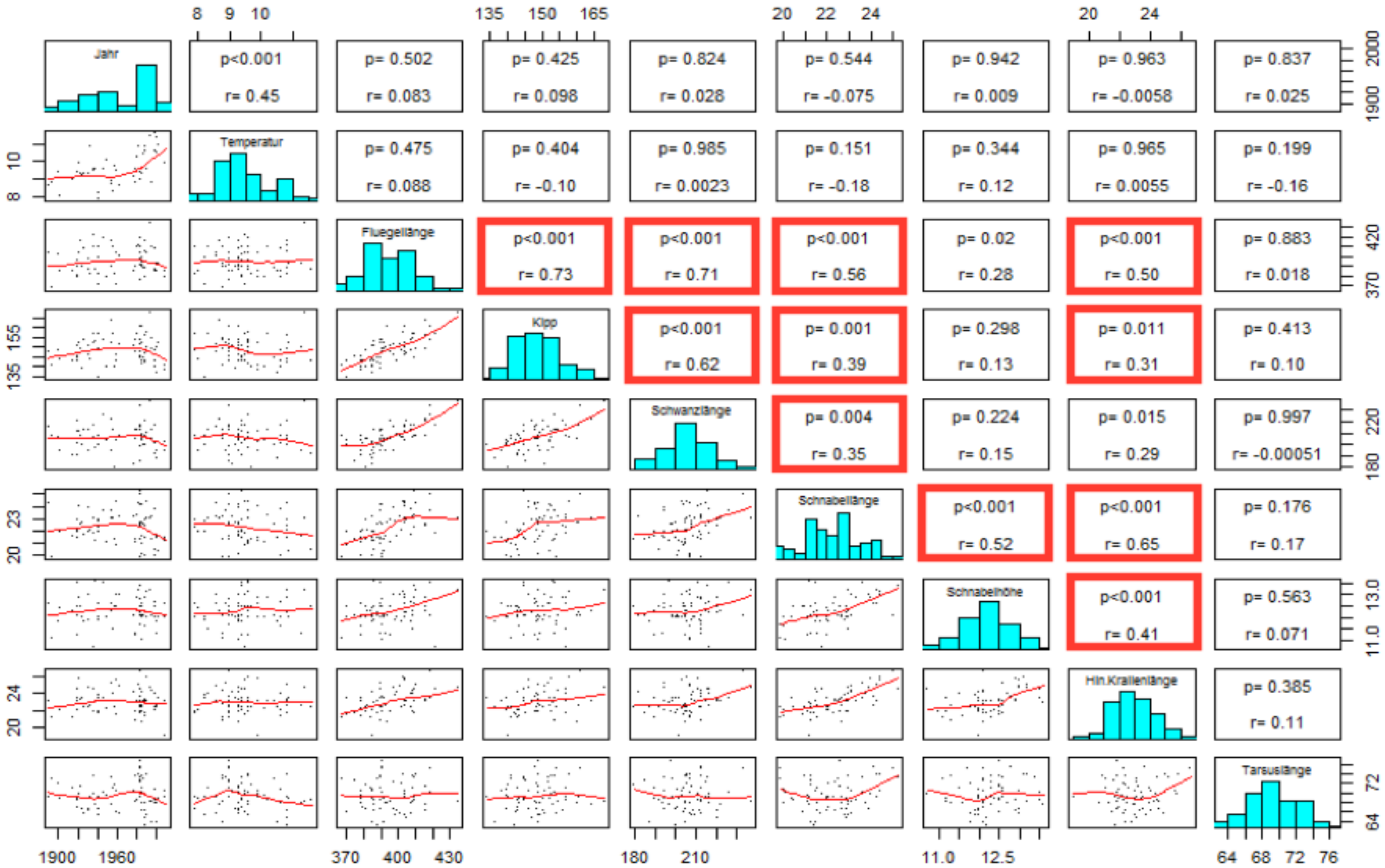
Appendix 18: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European adult female Buzzards. Significant values are marked red.



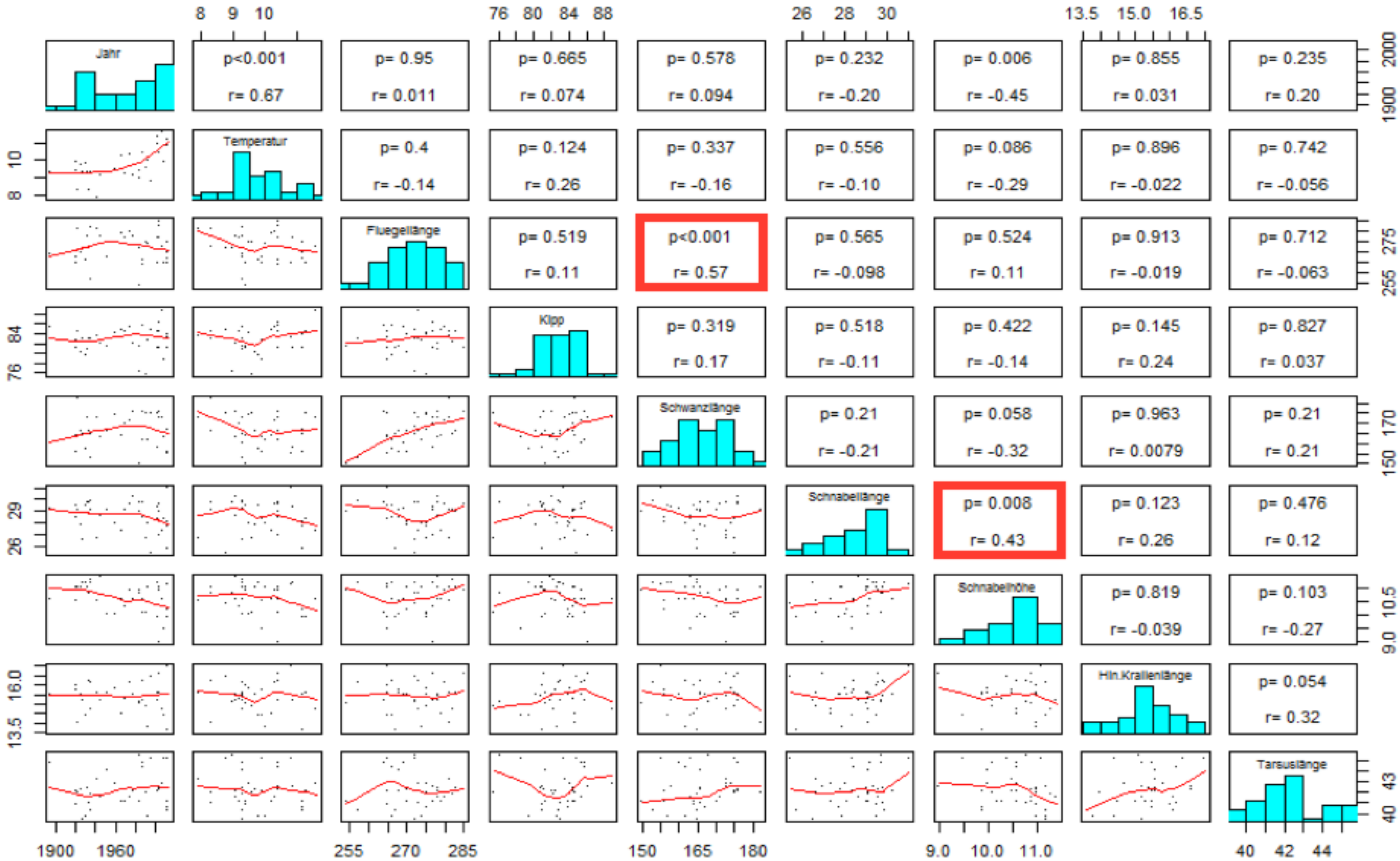
Appendix 19: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European juvenile female Buzzards. Significant values are marked red.



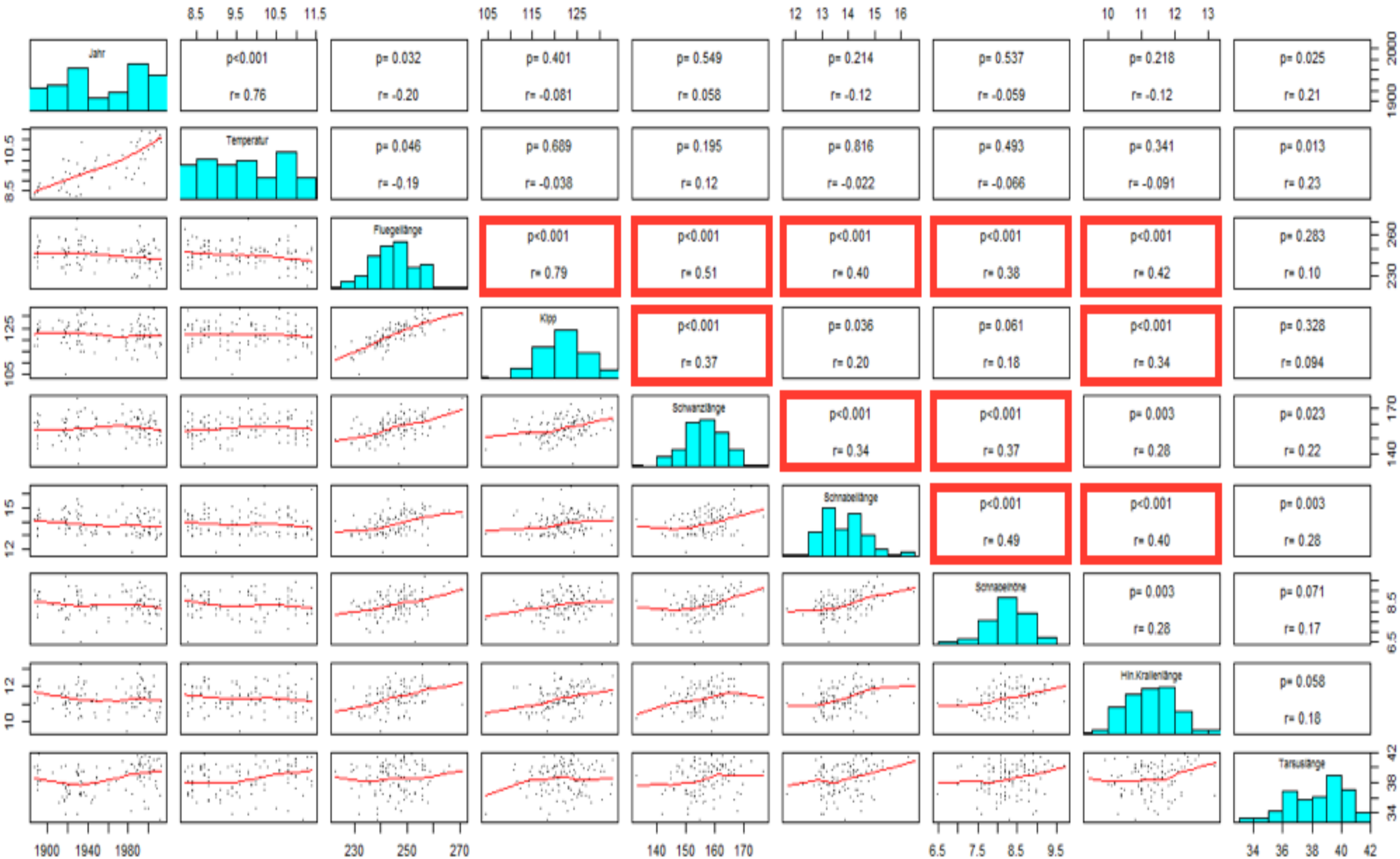
Appendix 20: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European adult male Buzzards. Significant values are marked red



Appendix 21: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European juvenile male Buzzards. Significant values are marked red

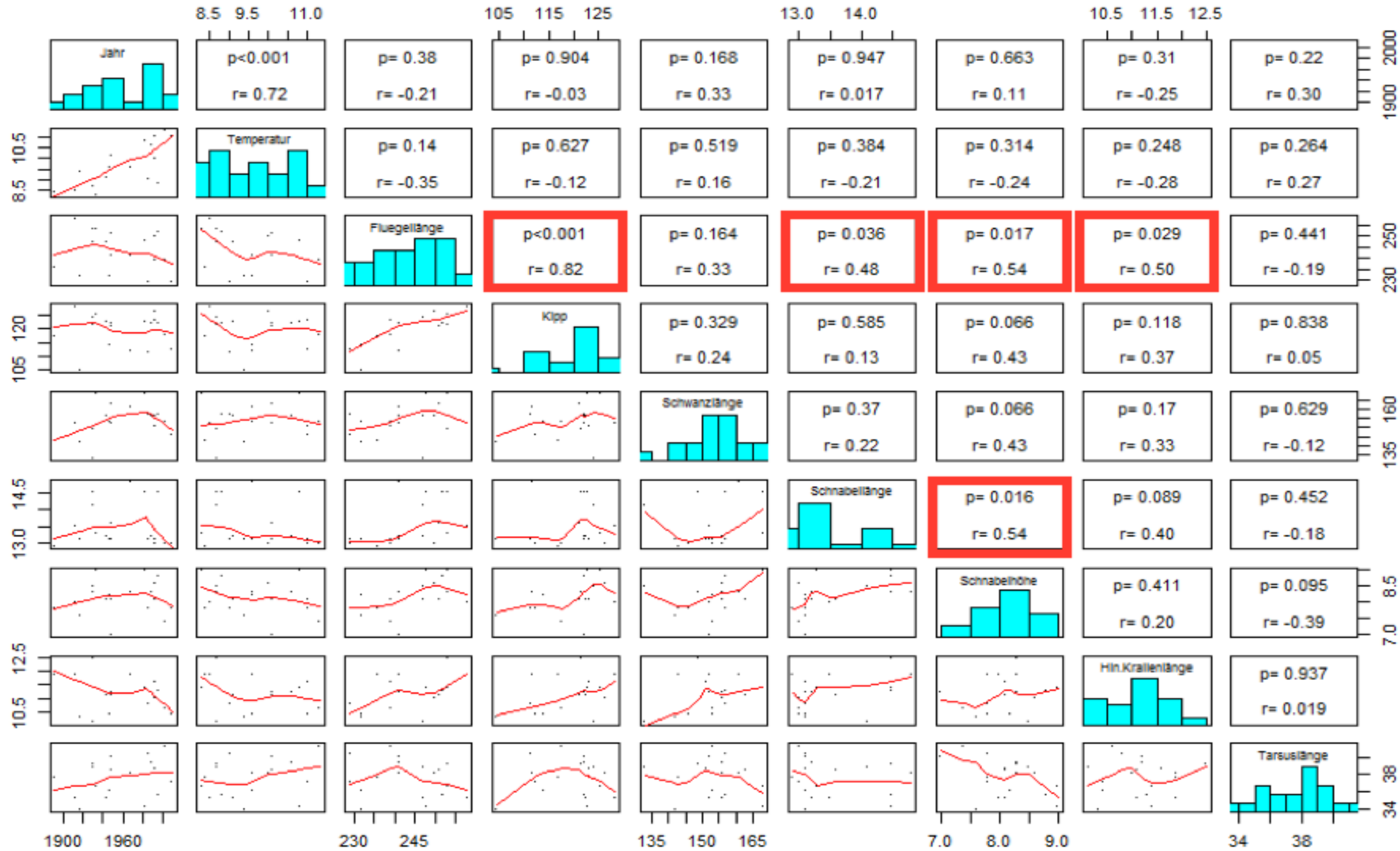


Appendix 22: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European Kestrels. Significant values are marked red.



Appendix 23: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European adult female Kestrels. Significant values are marked red.

Appendix 24: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European juvenile female Kestrels. Significant values are marked red.



Appendix 25: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European male adult Kestrels. Significant values are marked red.

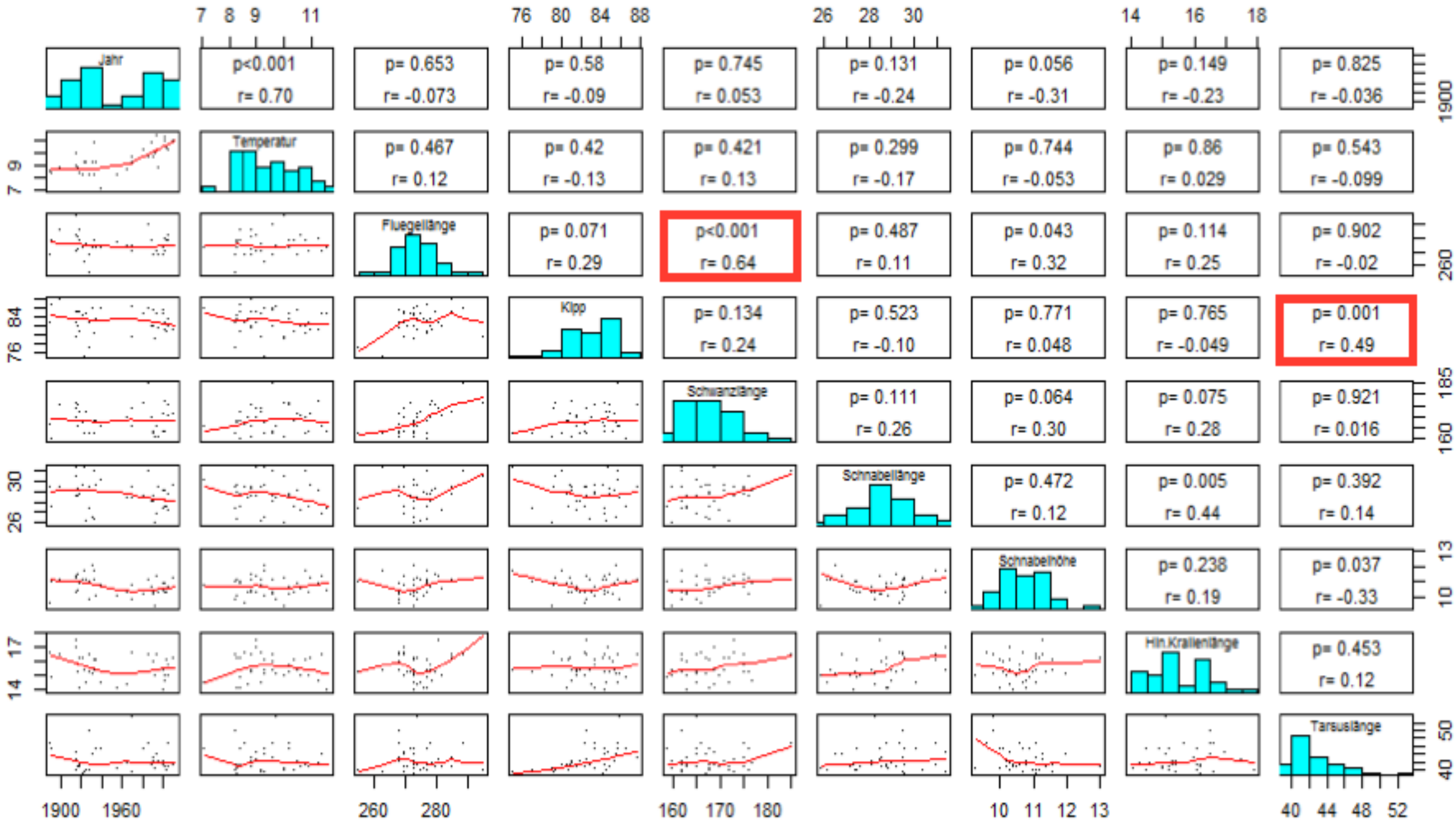
Appendix 26: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European juvenile male Kestrels. Significant values are marked red.

Appendix 27: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological characters in Central European Tawny Owls. Significant values are marked red.

Appendix 28: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological charac-ters in Central European adult female Tawny Owls. Significant values are marked red.

Appendix 29: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological charac-ters in Central European juvenile female Tawny Owls. Significant values are marked red.

Appendix 30: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological charac-ters in Central European adult male Tawny Owls. Significant values are marked red.



Appendix 31: Overview of the correlations between morphological characters in relation to time (1880-2015) and temperature as well as correlations between single morphological charac-ters in Central European juvenile male Tawny Owls. Significant values are marked red.