

A Review of Colour Phenotypes of the Eastern Red-backed Salamander, *Plethodon cinereus*, in North America

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The Eastern Red-backed Salamander (*Plethodon cinereus*) is the most abundant salamander species in many forests of north-eastern North America. It is well-known for its colour polymorphism, which includes eight colour phenotypes: the red-backed (striped), lead-backed (unstriped) and erythristic morphs, as well as the iridistic, albino, leucistic, amelanistic and melanistic anomalies. Here we review the various colorations of *P. cinereus*, with the objective of facilitating the identification of these different phenotypes and of generating interest among field herpetologists and scientists reporting on this species. We also list six previously unpublished occurrences of colour variants in this species (1 case of erythristism, 3 of iridism, 1 of leucism, and 1 of partial leucism). To our knowledge, these cases include the first documented occurrence of iridism in the red-backed morph of *P. cinereus*, and the first two mentions of this colour anomaly in the lead-backed morph from Canada.

Key Words: Phenotypes; coloration; red-backed; lead-backed; erythristic; colour morph; iridistic; albino; leucistic; amelanistic; melanistic; colour anomaly; Eastern Red-backed Salamander; *Plethodon cinereus*; North America

Introduction

Of all North American amphibians, the Eastern Red-backed Salamander (*Plethodon cinereus*) is probably one of the most studied species, because of its wide distribution and abundance in forests of eastern Canada and northeastern United States (Highton 1962; Burton and Likens 1975; Petranka 1998), its ecological role (Burton and Likens 1975; Wyman 1998), and its potential as indicator of climatic change (Lotter and Scott 1977; Gibbs and Karraker 2006) and habitat disturbances (deMaynadier and Hunter 1995) in forest ecosystems. Striking colour polymorphism of this salamander species has long attracted the attention of scientists, herpetologists, and naturalists. Three pigment cell classes, or chromatophores, are responsible for skin coloration in amphibians (Bagnara 1966; Taylor and Bagnara 1972): melanophores (brown to black pigment cells), xanthophores (yellow and red (erythrophores) pigment cells), and iridophores, which produce the shiny iridescent and reflecting aspect of the amphibian skin.

In this article, we review the state of knowledge for each of the eight colour phenotypes known to date in *P. cinereus*, which include the red-backed (striped), lead-backed (unstriped) and erythristic morphs, as well as the iridistic, albino, leucistic, amelanistic and melanistic anomalies. Our objective is to provide a standardized description accompanied by photographs for the colour phenotypes reported for *P. cinereus*. Characteristics useful to discriminate among these different phenotypes are summarized. The North American distribution of the different colour morphs and anomalies in *P. cinereus* is also provided. Finally, we report six previously unpublished phenotype occurrences in this species (1 of ery-

thristism, 3 of iridism, 1 of leucism, and 1 of partial leucism).

Colour Morphs

The red-backed and lead-backed colour morphs

The red-backed and lead-backed morphs (Figure 1) are the two most abundant phenotypes in *P. cinereus*. The ventral body of both morphs is coarsely mottled with black and white, resulting in a distinctive “salt-and-pepper” appearance (Figure 2; Table 1; Appendix). Individuals with intermediate colorations or other variations between these two morphs have been observed (e.g., Figure 3; Sipes 1964). The mid-dorsal stripe of the red-backed morph is generally red-orange, with gray-black borders that become mottled with white along the lower half of the body sides. Mid-dorsal stripe colours other than red-orange, such as shades of brown, gray, pink, white, and yellow have also been observed (e.g., Figures 4, 5; Bishop 1941; Test and Bingham 1948; Reed 1955; Schueler 1975; Hulse *et al.* 2001). Colour variations also include individuals with stripes that occur in disconnected sections along the body, and others with only continuous stripes on the tail (Bishop 1941; Cook 1967; Petranka 1998). The dorsum of the lead-backed morph does not exhibit stripes, and the coloration is generally a uniformly pigmented gray-black, but sometimes olive-gray or chestnut-brown (e.g., Figure 6; Klemens 1993). The dorsal-lateral body often exhibits some degree of iridescent or metallic, blue (Sawyers and Novick 2011), brassy, golden, shades of green or silver flecks (e.g., Figure 7).

Burger (1935) was the first to publish evidence that both morphs could be found in the same brood, which

TABLE 1. Main characteristics of the 8 colour phenotypes of the Eastern Red-backed Salamander (*Plethodon cinereus*).

Phenotype	Dorsal stripe	Dorsal-lateral body	Ventral body	Iris
Red-backed	Continuous or discontinuous red-orange stripe; sometimes shades of brown, gray, pink, white or yellow	Gray-black	“Salt-and-pepper” appearance	Normal (dark) pigmentation
Lead-backed	Unstriped	Gray-black; sometimes olive-gray or chestnut-brown	“Salt-and-pepper” appearance	Normal (dark) pigmentation
Erythristic	Unstriped	Red or orange, with or without black mottling	Red or orange	Normal (dark) pigmentation
Iridistic	Stripe present or absent	Generalized iridescent flecking (brassy, golden, shades of green or silver)	“Salt-and-pepper” appearance with or without iridescent flecking	Normal (dark) pigmentation
Albino	Unstriped	Pink-white to white	Pink-white to white, translucent	Red-pink
Leucistic	Unstriped	Pink-white to white	Pink-white to white, translucent	Normal (dark) pigmentation
Amelanistic	Peach-red, orange or peach-yellow	Pink-white to white	Pink-white to white, translucent	White to normal (dark) pigmentation
Melanistic	Unstriped	Black	Black, translucent	Brown to black

showed that they are of the same species (Highton 1959). Both morphs can be found across the species range, throughout southeastern Canada and the eastern United States (Petranka 1998), but in very different proportions (Moore and Ouellet 2014). In some areas, both morphs are abundant, while in others, one or the other is more abundant. Monomorphic red-backed populations are not uncommon, while in other cases, red-backed individuals can be scarce or absent (Thurrow 1955; Highton 1959; Pflingsten and Walker 1978; Reichenbach 1981; Fisher-Reid *et al.* 2013). The red-backed morph has been reported in five Canadian provinces and 22 American states (Table 2), which represents the distribution range of this species. Kentucky, Minnesota, and Tennessee are at the limit of the species' range and the lead-backed morph of *P. cinereus* has not been reported there.

In the last decades, studies have suggested that the lead-backed morph of *P. cinereus* is more closely associated with warmer climates than the red-backed morph (Lotter and Scott 1977; Moreno 1989; Gibbs and Karraker 2006; Anthony *et al.* 2008). However, it seems that the possible role of climate in the distribution of the lead-backed morph has never been unanimously recognized; some doubts still persist in the scientific community about the validity of using this morph as indicator of climatic changes (Angleberger and Chinnici 1975; Pflingsten and Walker 1978; Petrucci *et al.* 2006; Anthony *et al.* 2008). Based on new discoveries in the northern areas of the species' range and on the largest compilation ever made for this species, Moore and Ouellet (2014) demonstrate however that climate and geographic variables do not influence

the colour morph proportions in *P. cinereus* populations. Fitzpatrick *et al.* (2009) mentioned that the most reasonable hypothesis to explain the existence of visual polymorphism across a geographical and phylogenetic range as wide as that of *P. cinereus* is that selection acts directly on appearance. Local natural selection could explain the morph frequency in given areas.

The erythristic colour morph

Erythrism (from Greek *eruthros*, red) refers to an excessive production and deposition of red or orange pigments (erythrophones). The erythristic morph of *P. cinereus* (Figures 8, 9) is usually all red or orange, but may exhibit varying degrees of black mottling on its dorsal and lateral surfaces. The ventral surface is generally red, orange or pink (Reed 1955; Thurrow 1961). Some intermediate colorations (partial erythrism) also exist (e.g., Figure 10). The erythristic morph has been found in four provinces (Brown 1928; Bleakney and Cook 1957; Cook and Bleakney 1961; Rosen 1971) and 10 states (Reed 1908; Reed and Wright 1909; Barbour 1914; Burt 1945; Matthews 1952; Pflingsten 1969; Mueller and Himchak 1983; deMaynadier 1995; McDonald *et al.* 2011), but it is more frequently found in United States than in Canada. The prevalence of this morph in the United States can sometimes be as high as 35-50% (Pauley *et al.* 2001; Cassell and Jones 2005), but generally rarely exceeds 20% (Lotter and Scott 1977; Tilley *et al.* 1982). According to Pauley *et al.* (2001), the distribution of this morph would be limited to cooler climates of glaciated areas of southern Canada and the northeastern United States. In this context, the apparent rarity of the erythristic morph in eastern Canada remains enigmatic. Thirty-seven erythristic



FIGURE 1. Red-backed (striped) and lead-backed (unstriped) morphs of the Eastern Red-backed Salamander (*Plethodon cinereus*) from Québec. Photo: M. Ouellet.



FIGURE 2. Distinctive "salt-and-pepper" appearance of the ventral body of a lead-backed morph of *P. cinereus* from Québec. Photo: M. Ouellet.



FIGURE 3. Slight colour variation of a red-backed morph of *P. cinereus* from Québec. Photo: M. Ouellet.



FIGURE 4. Cream coloration of the dorsal stripe of a red-backed morph of *P. cinereus* from New Hampshire. Photo: D. J. Hocking.



FIGURE 5. Shade of gray coloration of the dorsal stripe of a red-backed morph of *P. cinereus* from Ohio. Photo: C. D. Anthony.



FIGURE 6. Chestnut coloration of a lead-backed morph of *P. cinereus* from Québec. Photo: M. Ouellet.



FIGURE 7. A lead-backed morph of *P. cinereus* with blue iridophores from Maine. Photo: D. E. Swann.



FIGURE 8. An erythristic morph of *P. cinereus* from Québec. Photo: P. Beaupré.



FIGURE 9. Another example of erythrism of *P. cinereus*, with black mottling on the tail, from Nova Scotia. Photo: R. Merrick.



FIGURE 10. A partially erythristic morph of *P. cinereus* from New Hampshire. Photo: D. J. Hocking.



FIGURE 11. An iridistic colour anomaly of a red-backed morph of *P. cinereus* from North Carolina. Photo: L. A. Williams.



FIGURE 12. Iridism of a lead-backed morph of *P. cinereus* from Nova Scotia. Photo: J. Gilhen.



FIGURE 13. An albino colour anomaly of *P. cinereus* from Nova Scotia. Photo: J. Gilhen.



FIGURE 14. A leucistic colour anomaly of *P. cinereus* from Québec. Photo: L. Bouthillier.



FIGURE 15. Another example of leucism of *P. cinereus* from Nova Scotia. Photo: J. Gilhen.



FIGURE 16. Dorsal view of a partially leucistic *P. cinereus* from Québec. Photo: P. Beaupré.



FIGURE 17. Ventral view of the previous specimen of a partially leucistic *P. cinereus*, showing the translucent aspect of the body. Photo: P. Beaupré.



FIGURE 18. A partially leucistic *P. cinereus* from Ohio. Photo: C. D. Anthony.



FIGURE 19. An amelanistic colour anomaly of *P. cinereus* from Québec. Photo: J.-D. Moore.



FIGURE 20. Another example of amelanism of *P. cinereus* from Ohio (the red-eye effect is due to the photographic flash). Photo: J. G. Davis.

individuals have been reported in Canada (e.g., Piersol 1909; Gilhen 1968; Rosen 1971; Westell and Ross 1974; Jongsma 2012a), including a new occurrence for Québec (Figure 8). This specimen was observed in October 2005 in the La Haute-Yamaska Regional County Municipality, Québec (45°21'20"N, 72°37'18"W; datum = NAD83). Jongsma (2012a) reported 11 erythristic individuals among 85 *P. cinereus* specimens in Fredericton, New Brunswick, thus demonstrating that some salamander populations in eastern Canada could nevertheless show a high prevalence of erythrism.

Thurow (1955) mentioned that the nature of the erythristic form and its distribution suggest that genetic rather than environmental factors are involved. According to his interpretation, this phenotype could result from the action of a mutant allele that quantitatively inhibits the development of melanin (or possibly melanophores). For intermediate colorations of this morph, the author noted the possibility of only partial dominance or the involvement of more than one locus. Other studies suggested that erythristic *P. cinereus* may be the Batesian mimic of the Eastern Newt (*Notophthalmus viridescens*) at the elf stage (Lotter and Scott 1977; Tilley *et al.* 1982; Cassell and Jones 2005), which is known to be toxic for potential predators (Brodie *et al.* 1974). This phenomenon would partly explain the high abundance of the erythristic morph in some forests where the red eft is present. However, the presence of the red eft in northern forests does not necessarily imply

that the erythristic morph will be found in these ecosystems (Moore *et al.* 2012).

Colour Anomalies

The iridistic colour anomaly

Iridism in amphibians is defined as the excessive production and deposition of iridophore platelets. Individuals are characterized by generalized iridescent or metallic, brassy, golden, shades of green or silver flecks on their dorsal-lateral body. This condition has previously been described (Muchmore 1955; Hertzler 1958) and reported for the lead-backed morph of *P. cinereus* in the United States (Bogert 1952; Highton 1962, 1972; Schueler 1975; Klemens 1993; Hulse *et al.* 2001; Gibbs *et al.* 2007). However, it was not always clear from these documents whether the iridescent flecking was very abundant or visible only upon close examination. Muchmore (1955) noted that microscopic examination revealed that this flecking was due to numerous individual iridophores located around the melanophores. These flecks are also known to fade rapidly on preserved specimens (Grobman 1949; Muchmore 1955; Pfungsten and Downs 1989).

We report here three previously unpublished occurrences of iridistic *P. cinereus*, including, to our knowledge, the first documented occurrence of iridism in the red-backed morph and the first two mentions in lead-backed morphs from Canada. In all these cases, the dorsal body exhibited abundant, continuous, and

TABLE 2. North American distribution of the 8 different colour morphs and anomalies of the Eastern Red-backed Salamander (*Plethodon cinereus*). Abbreviations: Red = red-backed morph, Lea = lead-backed morph, Ery = erythristic morph, Iri = iridistic anomaly, Alb = albino anomaly, Leu = leucistic anomaly, Ame = amelanistic anomaly, Mel = melanistic anomaly.

Province or State	Red	Lea	Ery	Iri	Alb	Leu	Ame	Mel
Connecticut								
Delaware								
Illinois								
Indiana								
Kentucky								
Maine								
Maryland								
Massachusetts								
Michigan								
Minnesota								
New Brunswick								
New Hampshire								
New Jersey								
New York								
North Carolina								
Nova Scotia								
Ohio								
Ontario								
Pennsylvania								
Prince Edward Island								
Québec								
Rhode Island								
Tennessee								
Vermont								
Virginia								
West Virginia								
Wisconsin								

large iridescent brassy flecks. The first individual (Figure 11) was observed in September 2012 in Ashe County, North Carolina (36°25'35"N, 81°35'26"W; datum = WGS84), and the second (Figure 12) was reported in June 1982 in Colchester County, Nova Scotia (45°23'37"N, 63°55'04"W; datum = NAD83). The third specimen was observed in October 2013 in the Antoine-Labelle Regional County Municipality, Québec (46°43'03"N, 75°33'06"W; datum = NAD83). These occurrences show that iridescent flecking is sometimes quite abundant and may represent the dominant colour in some *P. cinereus* individuals. Added with cases from other studies (e.g., Muchmore 1955), they also suggest that iridism in *P. cinereus* is probably more common than previously reported, and thus deserves to be regarded as a noteworthy colour variant. To date, it has been reported in two provinces and 9 states

The albino colour anomaly

Albinism (from Latin *albus*, white) is defined as the total absence of pigmentation formation in the skin and irises. The albino *P. cinereus* is unstriped and characterized by a flesh-colored body (pink-white to white) and red-pink irises (Figure 13). According to the literature, this anomaly has been observed three times in

Canada (Milnes 1946; Moore *et al.* 2012) and three times in the United States (Fowler 1942; Hensley 1959; Harris 1968a), though no detailed description of the specimens was given by Milnes (1946) nor Harris (1968a). The only case mentioned in Québec (Moore *et al.* 2012) has been redefined as an amelanistic *P. cinereus*, after the photographic verification showed normal (dark) pigmentation of the irises, a light orange dorsal stripe and the pink-white colour of the specimen's dorsal-lateral body. Similarly, the albino case reported by Harris (1968b) was redefined as an amelanistic, based on a published photograph (Zahl 1972).

The leucistic colour anomaly

Leucism (from Greek *leukos*, white) is a defect in the skin causing an inability to support any type of skin pigments. Since all types of skin pigments are thus reduced, leucistic individuals resemble albino *P. cinereus* (Figures 14, 15), except for their normally pigmented irises. This explains why this condition has also been defined in the past as "albinos with orbital melanophores" (Brame 1962), or "partial albinos" (Gilhen 1986). The leucistic anomaly has been observed four times in Canada (Gilhen 1986 (based on the colour photo NSM973-634-1); Rye 1991; Lamond 1994; Jongma 2012b) and six times in the United States (Wilmott

1945; Pauley 1974; Lotter and Scott 1977 (white partial albino); Mitchell and Mazur 1998; Mendyk *et al.* 2010). A previously unpublished occurrence of leucism (Figure 14) was observed in September 2013 in the Thérèse-De Blainville Regional County Municipality, Québec (45°39'28"N, 73°54'33"W; datum = NAD83). An unpublished occurrence of partial leucism (Figures 16, 17) was also reported in September 2005 in the Nouvelle-Beauce Regional County Municipality, Québec (46°32'30"N, 71°00'01"W; datum = NAD83). Leucism was considered as partial in this specimen, due to the presence of melanophores. Two similar cases have also been described in Ohio (Figure 18, Paluh *et al.* 2013).

The amelanistic colour anomaly

Amelanism is a condition characterized by the lack of melanin production. The appearance of this anomaly on the skin depends on the remaining non-melanin pigments. Although similar, amelanistic *P. cinereus* salamanders may retain more coloration than the albino and leucistic anomalies, and are characterized by a body without black pigmentation (Figures 19, 20). The dorsal stripe is typically pale in colour, usually peach-red, orange or peach-yellow. The dorsal-lateral body is often pink-white to white, the ventral body is sometimes translucent, and the iris colour may vary from white to normal (dark).

This colour anomaly has been reported five times in eastern Canada (Gilhen 1986 (based on the colour photo to NSM984-108-1); Moore and Gilhen 2011; Russell *et al.* 2011; see also the above section on the albino anomaly), and twice in the United States (Davis 2009; see also the above section on the albino anomaly). Some authors may sometimes have considered the amelanistic condition as partial albinism, using terminology such as “albinos with xanthophores” or “partial albino with xanthophores” and “albinos with erythrophores” or “partial albino with erythrophores” (Brame 1962; Harris 1970; Dyrkacz 1981).

The melanistic colour anomaly

Melanism (from Greek *melas*, black) is a condition characterized by an overabundance of melanin pigments (melanophores) production and deposition. Melanistic individuals are usually totally black, including the ventral body and irises. This condition is somewhat the opposite of amelanism. This anomaly in a *P. cinereus* was first mentioned in Québec (Moore *et al.* 2012). With its uniformly black and translucent belly, the melanistic individual is relatively easy to distinguish from the lead-backed morph (occasionally very dark), which has a salt-and-pepper belly appearance. The melanistic anomaly is not new and has already been encountered in other salamander and anuran species, in which the ventral body is sometimes translucent (Dubois, 1979).

Conclusion

Eight colour phenotypes of the woodland salamander *P. cinereus* have been reported to date. These

include main colour morphs as well as rarer colour anomalies. To discriminate among these different phenotypes, useful characteristics are summarized in Table 1, and a dichotomous key is provided (Appendix). Contrary to amphibian malformations that are mostly found in young individuals and rarely in adults because they are maladaptive (Ouellet 2000), most of the *P. cinereus* specimens encountered that exhibit colour anomalies are adults. We agree with Mendyk *et al.* (2010) that these colour conditions may be less detrimental for this secretive species than for other amphibians, and thus more likely to be present.

We hope that this article and the greater accessibility of digital photography will encourage documenting these atypical cases in future inventories. We suggest using uniform colour names based on an easily-accessible online list of colours (Wikipedia 2014). This list is preferred over other guides (e.g., Smithe 1975) which are rather more difficult to obtain. An ongoing colour photo gallery is currently online for recognition and comparison purposes (<http://www.amphibia-nature.org/en/projects/amphibians-reptiles/colorations-plethodon/>). Photos of unusual colorations with the date, location, and details about the observation can be sent to the following address: info@amphibia-nature.org. Close-up pictures that show the colour of the dorsal stripe, dorsal-lateral body, ventral body, and irises are preferred.

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Appendix

Dichotomous key of the 8 different colour phenotypes of the Eastern Red-backed Salamander (*Plethodon cinereus*).

- 1.a Presence of a continuous or discontinuous dorsal stripe: 2
- 1.b Absence of a dorsal stripe: 4
- 2.a Presence of melanophores on the skin surface: 3
- 2.b Absence of melanophores, dorsal-lateral body pink-white to white: **Amelanistic anomaly** (Figures 19, 20)
- 3.a Generalized iridescent flecking: **Iridistic anomaly** (Figure 11)
- 3.b No generalized iridescent flecking: **Red-backed morph** (Figures 1-5)
- 4.a Presence of melanophores on the skin surface: 5
- 4.b Absence of skin melanophores: 8
- 5.a Presence of red or orange pigmentation: **Erythristic morph** (Figures 8-10)
- 5.b Absence of red pigmentation: 6
- 6.a "Salt-and-pepper" appearance of the ventral body: 7
- 6.b Black and translucent ventral body: **Melanistic anomaly**
- 7.a Generalized iridescent flecking: **Iridistic anomaly** (Figure 12)
- 7.b No generalized iridescent flecking: **Lead-backed morph** (Figures 1, 2, 6, 7)
- 8.a Red-pink pigmentation of the irises: **Albino anomaly** (Figure 13)
- 8.b Normal (dark) pigmentation of the irises: **Leucistic anomaly** (Figures 14-18)