Journal of Crustacean Biology, 2023, **43**, 1–5
https://doi.org/10.1093/jcbiol/ruad043
Advance access publication 1 August 2023
Research Note

The Crustacean Society
OXFORD

First record of leucism in a primary burrowing crayfish: *Distocambarus crockeri* Hobbs & Carlson, 1983 (Decapoda: Astacidea: Cambaridae) from South Carolina, USA

Megan B. Stubbs[1], Hogan D. Wells[1], Zanethia C. Barnett[2], Michael R. Kendrick[3], Zachary J. Loughman[1] and Zackary A. Graham[1]

[1]West Liberty University, Department of Organismal Biology, Ecology, and Zoo Sciences, West Liberty, WV 26074, USA
[2]Southern Research Station, USDA Forest Service, Center for Bottomland Hardwoods Research, Oxford, MS 38655, USA
[3]South Carolina Department of Natural Resources, Marine Resources Research Institute, Charleston, SC 29412, USA

Correspondence: Z.A. Graham; zackary.graham@westliberty.edu

ABSTRACT

The piedmont prairie burrowing crayfish, *Distocambarus crockeri* Hobbs & Carlson, 1983, is a primary burrowing crayfish endemic to South Carolina, USA. The species is the most widely distributed and studied of the five species of *Distocambarus* Hobbs, 1981. Surveys have clarified the species distribution and habitat, but, like other burrowing crayfishes, our understanding of its ecology is lacking. We report the discovery of two leucistic specimens of *D. crockeri* collected in an ephemeral pool in a roadside ditch on 14 March 2022 in Edgefield County, South Carolina. To the best of our knowledge, our discovery represents the first documented case of leucism in a primary burrowing crayfish. We discuss the significance of this observation in relation to other recorded observations of color anomalies throughout crayfishes as well as potential environmental causes of leucism.

KEYWORDS: albinism, color abnormalities, color morphs, crayfish color, Crustacea, color mutations, pigments

Freshwater crayfishes are recognized as ecosystem engineers and keystone species (Crocker & Barr, 1968; Momot *et al.*, 1978; Creed, 1994; Momot, 1995; Usio, 2000), mostly because of their burrowing ability. Hobbs (1981) assigned crayfishes into three burrowing categories based on behavior: tertiary, secondary, and primary. Tertiary and secondary burrowing crayfishes construct relatively simple burrows with a single vertical tunnel that remains connected to perennial lentic or lotic surface waters. Tertiary and secondary burrowing crayfishes often only burrow when sheltering themselves from predators, avoiding desiccation, or when reproducing. Conversely, primary burrowing crayfishes spend the majority of their lives within and around their terrestrial burrows and do not require a direct connection to perennial surface waters. Primary burrowing crayfishes construct complex burrows which often exhibit multiple portals (surface openings for burrows), tunnels, and chambers that can occur significant distances from permanent bodies of water (Hobbs, 1981). Unsurprisingly, with over 150 described species of primary burrowing crayfishes, their secluded underground lifestyle has thus far resulted in a poor understanding of their biology. According to the International Union for Conservation of Nature (IUCN), 19.5% of primary burrowing crayfishes are categorized as being data deficient, but 12.9% of primary burrowers have not been evaluated (Bloomer *et al.*, 2021; IUCN, 2022).

One unanswered question relating to primary burrowing crayfishes relates to their coloration and color patterns (Schuster, 2020). Despite spending a majority of their lives underground, primary burrowing crayfishes can exhibit vibrant colors, with many species displaying conspicuous red, orange, and blue colors and distinct color patterns (Schuster, 2020). The function of such vibrant colors and conspicuous patterns in primary burrowing crayfishes remains unknown, but it has been speculated to be important in intra/interspecific competition, communication, camouflage, and species identification (Schuster, 2020). Although some primary burrowing crayfishes may possess conspicuous coloration, other primary burrowing crayfishes exhibit inconspicuous, drab colorations, like many tertiary and secondary burrowing crayfishes. Tertiary and secondary burrowing crayfishes often display coloration that provides camouflage and advantages for life in open-water stream habitats, where they are presumably exposed to increased predation pressures compared

Received 16 May 2023; Accepted 10 July 2023

to primary burrowers (Kent, 1901; Thacker *et al*., 1993; Füreder & Machino, 2002; Sacchi *et al*., 2021).

Atypical colors phenotypes and color patterns have been documented in several species of crayfishes, although almost entirely within tertiary and secondary burrowers. For instance, an individual of *Cambarus bartonii bartonii* Fabricius, 1798 from eastern Pennsylvania was discovered with a bilaterally partitioned color phenotype with the left half of the body dark olive green and the right half light amber (Hartzell, 2017). A similar observation of color bilateralism was recorded in *Faxonius immunis* Hagen, 1870 (Dowell & Winier, 1969). Blue-color phenotypes appear to be common in crayfishes, with documented instances of atypical blue coloration appearing in three of four families: Cambaridae (*Procambarus clarkii* Girard, 1852, *P. hagenianus* Faxon, 1884, *P. acutus* Girard, 1852, *Cambarus carolinus* Erichson, 1846, and *Creaserinus hedgpethi* Hobbs, 1948), Parastacidae (*Cherax destructor* Clark, 1936), and Astacidae (*Pontastacus leptodactylus* Eschscholtz, 1823) (Hayes & Reimer, 1975; Walker *et al*., 2000; Schuster, 2020; Kale *et al*., 2021). Atypical color phenotypes are also popular in the pet trade, with orange phenotypes of *Cambarellus patzcuarensis* Villalobos, 1943 (Weiperth *et al*., 2017) and blue phenotypes of *Procambarus alleni* Faxon, 1884 being sold worldwide.

There are also several reports of individuals with white color phenotypes (see below), which may be a result from genetic conditions known as leucism and albinism. Albinism results from a genetic mutation in which there is a total absence of the pigment melanin (Lutz, 2008), resulting in an entirely white phenotype. By contrast, leucism, sometimes referred to as partial albinism, occurs when the majority, but not all, of the body exhibits a lack of melanin due to genetic mutation, resulting in a white phenotype with the possibility of pigmented features, such as the eyes (Sage, 1962; Jehl, 1985; Fleck *et al*., 2016). Although there is substantial confusion regarding the nomenclature of white-color aberrations (see van Grouw (2021) for a discission of these issues in birds), we discuss leucism following the definition provided above, in which a majority of the animal in question is white, but some regions may remain pigmented. Nevertheless, it is worth highlighting that crustacean coloration is believed to be primarily driven by carotenoid-based pigments, and not melanin-based pigments (Tlusty & Hyland, 2005; Wade *et al*., 2005). Still, we use the word leucism to describe these color phenotype aberrations in alignment with previous literature. Within natural populations of crayfishes, there are reports of leucism in *P. leptodactylus* (Kale *et al*., 2020), *P. clarkii* (Nakatani, 1999), *Faxonius propinquus* Girard, 1852 (Dunham *et al*., 1979) and *Faxonius rusticus* Girard, 1852 (Glon, 2016). Further, leucism is believed to result from a genetic mutation within a single locus (Owen & Skimmings, 1992; Fleck *et al*., 2016), which allows leucistic crayfish to be bred in the pet trade. For example, within the pet trade, leucistic or "white" *Procambarus clarkii* are widely available (Faulkes, 2015a, b; Putra *et al*., 2018). Unsurprisingly, within primary burrowing crayfishes, few observations of atypical coloration have been reported in the literature. While describing two new species of *Lacunicambarus*, Glon *et al*. (2020) commented on abnormalities in the base color for two banded mudbugs, *Lacunicambarus freudensteini* Glon *et al*., 2020: one specimen exhibited an abnormal powder blue coloration, whereas a second one exhibit pink coloration. Additionally, there are reports of a population of prairie crayfish, *Procambarus gracilis* Bundy in Forbes, 1876 in which many individuals possess blue coloration (Secker, 2013).

We report the discovery of two leucistic individuals of the piedmont prairie burrowing crayfish, *Distocambarus crockeri* Hobbs & Carlson, 1983, a primary burrowing crayfish endemic to South Carolina, USA. Individuals of this species are typically inconspicuous, being dark brown to grayish brown with stripes or patterning sometimes present. As one of the five species of *Distocambarus*, *D. crockeri* has the widest distribution, spanning

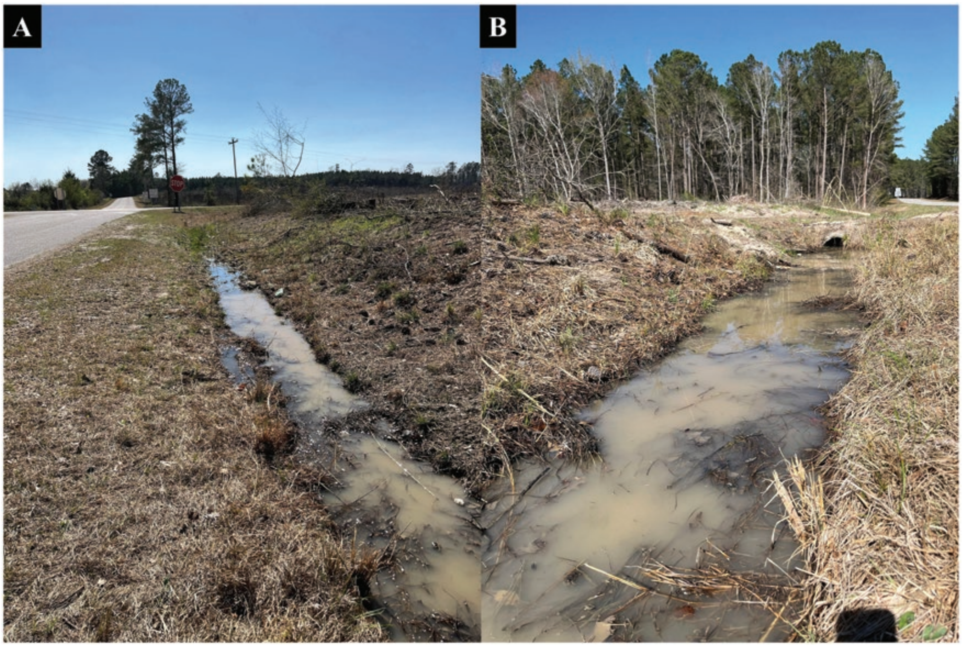

Figure 1. The roadside ditch where we collected two leucistic individuals of *Distocambarus crockeri* (**A**, **B**).

Edgefield, McCormick, Greenwood, and Saluda counties in South Carolina (Hobbs & Carlson, 1983; unpublished data).

Both leucistic individuals were collected in Edgefield County on March 2022, (33.921730, −82.126683) at a roadside ditch (RSD) site *D. crockeri* historically inhabited (Welch & Eversole, 2006). Intense anthropogenic manipulation from logging occurred at the site at the time of sampling (Fig. 1). Pine-tree management frequently occurs in Edgefield and surrounding counties, with clear-cutting as a common practice to initiate new plots for the timber industry. At the collection site, a culvert-fed pool approximately 25 m long × 1.5 m wide filled the RSD with approximately 12 cm of turbid water containing a large amount of trash. The entire RSD habitat had an open canopy and surrounding vegetation composed of grasses, sedges, and rushes, with evidence of mowing.

Because no visible surface burrows were detected, we collected individuals by dip-netting the entire length of the RSD six times to disturb any crayfish in the water column and increase our chances of collection. The first attempt resulted in the collection of two apparent leucistic individuals of *D. crockeri* (Fig. 2) in addition to many other typically colored individuals. *Distocambarus crockeri* was the only species collected at the site ($N = 68$). We presumed that both individuals were leucistic based on their clear-white unpigmented carapaces with the only pigmented

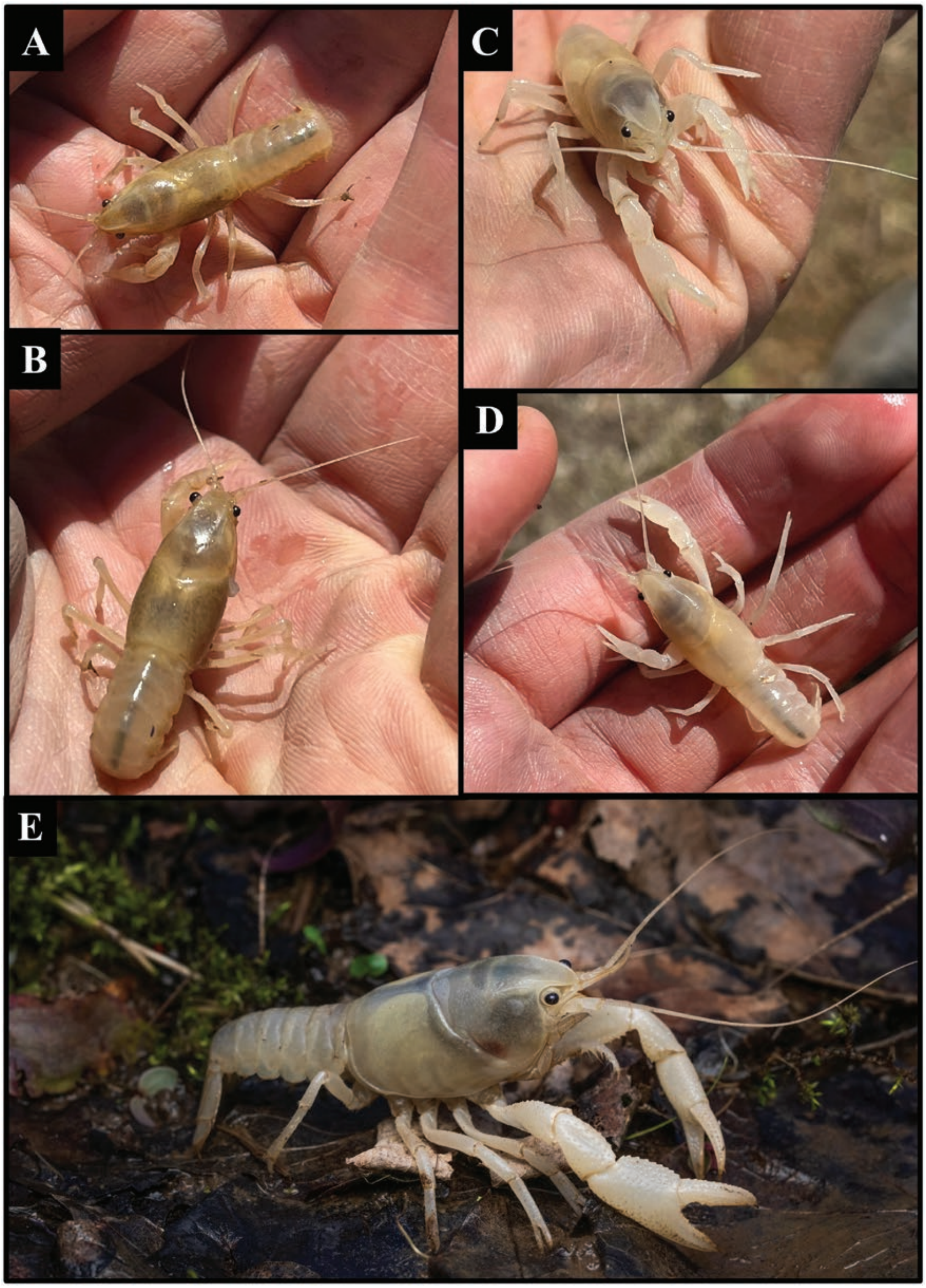

Figure 2. Female leucistic *Distocambarus crockeri* in situ (**A**, **B**); male leucistic individual in situ (**C**, **D**); male individual after a fourth molt in captivity at West Liberty University; photo by ZAG (**E**).

region of the body being their eyes. Both crayfishes appeared to have recently molted based on their exoskeleton pliability. We sexed each individual and measured their carapace length with digital calipers. One specimen was a form II male with a carapace length of 17.5 mm and the second a female with a carapace length of 16.33 mm and a regenerated right claw. Based on previously published data, both specimens were subadults (i.e., too small to reproduce; Eversole & Welch, 2013). The leucistic female did not survive beyond collection. The male, however, was taken to West Liberty University alive, where it has since molted five times.

While in captivity, the male *D. crockeri* was fed leaf-litter *ad libidum* in a 15 × 15 × 5.5 cm container. During this time, the crayfish's white exoskeleton slowly developed darker colors, but the dominant coloration remained white. After molting, the crayfish returned to the bright white coloration with pigmented eyes (Fig. 2E), which confirms leucism (as a genetic phenotype), ruling out the lack of dietary pigments as a cause of coloration. We acknowledge, however, that leaf litter alone may not have supplied the complete range of pigments available in the natural diet(s) of primary burrowing crayfishes. This discovery is the first reported case of leucism in a primary burrowing crayfish.

Although color abnormalities such as leucism are rarely reported in crayfishes, one population of leucistic *F. propinquus* is known to have co-occurred with typical colored individuals of the same species over 40 years in Lake Simcoe, Ontario, Canada (Dunham *et al.*, 1979; Jordan *et al.*, 1986; Hamr *et al.*, 2019). Since this leucistic *F. propinquus* population was first discovered, rusty crayfish *F. rusticus* have invaded Lake Simcoe and compete sympatrically (Bowles, 2009). Following the invasion of *F. rusticus*, the abundance of leucistic *F. propinquus* has dramatically decreased, with Hamr *et al.* (2019) recently collecting only six leucistic individuals, whereas Dunham *et al.* (1979) collected 119 in two days in 1977. Despite the recent decrease in population size, the Canadian population of leucistic *F. propinquus* demonstrates that leucism can occur and persist in natural populations for long periods despite the presumed disadvantage (such as increased vulnerability to predation or low genetic diversity) of leucistic phenotypes (Momot & Gall, 1971).

The occurrence of leucism in other taxa has been associated with mutations arising from radioactive pollution from a nuclear power plant (Ellegren *et al.*, 1997; Møller & Mousseau, 2001) and inbreeding (Owen & Skimmings, 1992; Bensch *et al.*, 2000), but the exact mechanism (i.e., physiological or genetic) causing such leucistic phenotypes is unknown. It is unclear if inbreeding is present in this population, or whether nuclear pollution is a likely cause of leucism in this instance. Nevertheless, it can be speculated that the recent impact of logging combined with substantial anthropogenic waste, such as plastic food bags and polystyrene foam cups and containers, in the particular habitat could have been the likely cause. We unfortunately did not collect water samples to determine water quality (e.g., dissolved oxygen, turbidity, nitrates, pH, and other potential factors). Because populations of primary burrowing crayfishes presumably have a reduced dispersal capacity and a reduced gene flow across populations compared to tertiary burrowing crayfishes (Hurt *et al.*, 2019; Clay *et al.*, 2020), the resulting atypical color phenotype from inbreeding may persist over time and eventually become common. It can also be hypothesized that the appearance of abnormal colorations in primary burrowing crayfishes may be related to the unknown function of conspicuous coloration (orange, red, blues, etc.) exhibited by many primary burrowing crayfish species. Primary burrowing crayfishes presumably face reduced predation pressure due to their burrowing lifestyle compared to tertiary or secondary burrowing crayfishes inhabiting a permanent body of water. Since atypical color phenotypes like leucism presumably arise due to genetic mutations or inbreeding, there may be little to no selection against this trait once they emerge. These ideas, however, are entirely speculative, but are a potentially fertile area of research that could elucidate the genetic and ecological mechanisms relating to crayfish color phenotypes and color abnormalities.

ACKNOWLEDGEMENTS

We would like to thank the West Liberty University Crayfish Conservation Laboratory for their sampling efforts. The authors thank Justin Sanclemente for his participation in the discovery of the leucistic crayfish. We also thank the anonymous reviewers for their contributions to improve the manuscript. All data collection was conducted under South Carolina Department of Natural Resources (SCDNR) permit F-22-013 and supported in part by U.S. Fish and Wildlife Service grant F21AF03627 awarded to SCDNR. This publication represents SCDNR Marine Resources Research Institute Contribution Number 867.

REFERENCES

Bensch, S., Hansson, B., Hasselquist, D. & Nielsen, B. 2000. Partial albinism in a semi-isolated population of great reed warblers. *Hereditas*, **133**: 167–170.

Bloomer, C.C., Distefano, R.J. & Taylor, C.A. 2021. A global review of life history studies on burrowing crayfish. *Crustaceana*, **94**: 357–379.

Bowles, B. 2009. *Invasive crayfish a plenty*. Orillia Packet and Times. Orillia, ONT, Canada.

Clark, E. 1936. The freshwater and land crayfishes of Australia. *Memoirs of the Natural Museum of Victoria*, **10**: 5–58.

Clay, M., Brannock, P.M., Barbour, M., Feminella, J.W., Santos, S.R. & Helms, B.S. 2020. Strong population structure and differentiation within and among burrowing bog crayfish species of southern Alabama wetlands. *Wetlands*, **40**: 1595–1606.

Creed, R.P. Jr. 1994. Direct and indirect effects of crayfish grazing in a stream community. *Ecology*, **75**: 2091–2103.

Crocker, D.W. & Barr, D.W. 1968. *Handbook of the crayfishes of Ontario*. University Toronto Press, Toronto, Canada.

Dowell, V.E. & Winier, L.P. 1969. A bilateral color anomaly in the crayfish, *Orconectes immunis* (Hagen). *Proceedings of the Iowa Academy of Science*, **76**: 487–492.

Dunham, D.W., Jordan, S.D. & Niglas, M. 1979. A new color morph of the crayfish *Orconectes propinquus* (Girard). *American Midland Naturalist*, **102**: 384–387.

Ellegren, H., Lindgren, G., Primmer, C.R. & Møller, A.P. 1997. Fitness loss and germline mutations in barn swallows breeding in Chernobyl. *Nature*, **389**: 593–596.

Erichson, W.F. 1846. Uebersicht der Arten der Gattung Astacus. *Archiv Fur Naturgeschichte*, **12**: 86–103.

Eschscholtz, F.F. 1823. Descriptio novae Astacorum speciei Rossicae. *Memoires de la Société Impériale des Naturalistes de Moscu*, **6**: 109–110.

Eversole, A.G. & Welch, S.M. 2013. Ecology of the primary burrowing crayfish *Distocambarus crockeri*. *Journal of Crustacean Biology*, **33**: 660–666.

Fabricius, J.C. 1798. *Supplementum Entomologiae Systematicae*. Proft & Storch, Hafniae [= Copenhagen].

Faulkes, Z. 2015a. Marmorkrebs (*Procambarus fallax f. virginalis*) are the most popular crayfish in the North American pet trade. *Knowledge and Management of Aquatic Ecosystems*, **416**: 1–15.

Faulkes, Z. 2015b. The global trade in crayfish as pets. *Crustacean Research*, **44**: 75–92.

Faxon, W. 1884. Descriptions of new species of *Cambarus*, to which is added a synonymical list of the known species of *Cambarus* and *Astacus*. *Proceedings of the American Academy of Arts and Sciences*, , **20**: 107–158.

Fleck, K., Erhardt, G. & Lühken, G. 2016. From single nucleotide substitutions up to chromosomal deletions: genetic pause of leucism-associated disorders in animals. *Berliner und Munchener Tierarztliche Wochenschrift*, **129**: 269–281.

Forbes, S.A. 1876. List of Illinois Crustacea: with descriptions of new species. *Bulletin of the Illinois State Laboratory of Natural History*, **1**: 3–72.

Füreder, L. & Machino, Y. 2002. A revised determination key of freshwater crayfish in Europe. *Berichte Des Naturwissenschaftlich-Medizinischen Vereins in Innsbruck*, **89**: 169–178.

Girard, C.F. 1852. A revision of the North American Astaci, with observations on their habits and geographic distribution. *Proceedings of Academy of Natural Sciences of Philadelphia*, **6**: 87–91.

Glon, M.G. 2016. Don't judge a crayfish by its cover: color morphs may render crayfish unidentifiable. *Crayfish News*, **38**: 8–9.

Glon, M.G., Adams, S.B., Loughman, Z.J., Myers, G.A., Taylor, C.A., & Schuster, G.A. 2020. Two new species of burrowing crayfish in the genus *Lacunicambarus* (Decapoda: Cambaridae) from Alabama and Mississippi. *Zootaxa*, **4802**: 401–439.

Hagen, H. 1870. Monograph of the North American Astacidae. *Illustrated Catalogue of the Museum of Comparative Zoology at Harvard College*, **3**: 1–109.

Hamr, P., Hoel, M. & Eales, K. 2019. The distribution and conservation status of the white colour morph of *Faxonius propinquus* (Northern Clearwater Crayfish) in Lake Simcoe, Ontario, Canada. *Freshwater Crayfish*, **24**: 33–38.

Hartzell, S. M. 2017. A bilaterally partitioned colour variant of an appalachian brook crayfish (*Cambarus bartonii bartonii*) from eastern Pennsylvania. *Canadian Field-Naturalist*, **131**: 335–337.

Hayes, W.A. & Reimer, R.D. 1975. Blue color anomaly in an Oklahoma crayfish (Decapoda, Cambaridae). *Proceedings of the Oklahoma Academy of Science*, **55**: 51.

Hobbs, H.H. 1981. The crayfishes of Georgia. *Smithsonian Contributions to Zoology*, **318**: 1–549.

Hobbs, H.H. Jr. 1948. A new crayfish of the genus *Cambarus* from Texas, with notes on the distribution of *Cambarus fodiens* (Cottle). *Proceedings of the United States National Museum*, **98**: 223–231.

Hobbs, H.H. Jr. & Carlson, P.H. 1983. *Distocambarus* (Decapoda: Cambaridae) elevated to generic rank, with an account of *D. crockeri*, new species, from South Carolina. *Proceedings of the Biological Society of Washington*, **96**: 420–428.

Hurt, C.R., Thoma, R.F., Withers, D.I., Williams, C.E. & Paine, R.T.R. 2019. Extensive regional endemism and cryptic diversity in the Tennessee and Kentucky, USA populations of the burrowing crayfish *Cambarus deweesae* (Bouchard & Etnier, 1979) (Decapoda: Astacidea: Cambaridae) as revealed by molecular genetics. *Journal of Crustacean Biology*, **39**: 440–449.

IUCN. 2022. *The IUCN Red List of Threatened Species*. Version 2022-1 [https://www.iucnredlist.org].

Jehl, J.R. 1985. Leucism in eared grebes in western North America. *The Condor*, **87**: 439–441.

Jordan, S.D., Dunham, D.W. & Jordan, N.W. 1986. A color morph of the crayfish *Orconectes Propinquus* (Girard) (Decapoda, Cambaridae). *Crustaceana*, **51**: 104–107.

Kale, S., Berber, S., Acarli, D., Demirkiran, T., Vural, P., Acarli, S., Kizilkaya, B. & Tan, E. 2020. First report of albinism in Turkish crayfish *Pontastacus leptodactylus* (Eschscholtz, 1823) (Crustacea, Decapoda, Astacidae). *Acta Natura et Scientia*, **1**: [https://doi.org/10.29329/actanatsci.2020.313.5].

Kale, S., Berber, S., Acarli, D., Demirkiran, T., Vural, P., Acarli, S., Kizilkaya, B. & Tan, E. 2021. Blue color anomaly in Turkish crayfish *Pontastacus leptodactylus* (Eschscholtz, 1823) (Crustacea, Decapoda, Astacidae) from Atikhisar Reservoir in Çanakkale, Turkey. *Acta Natura et Scientia*, **2**: [https://doi.org/10.29329/actanatsci.2021.314.1].

Kent, W.J. 1901. The colors of the crayfish. *American Naturalist*, **35**: 933–936.

Lutz, C.G. 2008. *Practical genetics for aquaculture*. Blackwell Science, Oxford.

Møller, A.P. & Mousseau, T.A. 2001. Albinism and phenotype of barn swallows (Hirundo rustica) from Chernobyl. *Evolution*, **55**: 2097–2104.

Momot, W.T. 1995. Redefining the role of crayfish in aquatic ecosystems. *Reviews in Fisheries Science*, **3**: 33–63.

Momot, W.T. & Gall, J.E. 1971. Some ecological notes on the blue color phase of the crayfish, *Orconectes virilis*, in two lakes. *Ohio Journal of Science*, **71**: 363–370.

Momot, W.T., Gowing, H. & Jones, P.D. 1978. The dynamics of crayfish and their role in ecosystems. *American Midland Naturalist*, **99**: 10.

Nakatani, I. 1999. An albino of the crayfish *Procambarus clarkii* (Decapoda: Cambaridae) and its offspring. *Journal of Crustacean Biology*, **19**: 380–383.

Owen, M. & Skimmings, P. 1992. The occurrence and performance of leucistic Barnacle Geese *Branta leucopsis*. *Ibis*, **134**: 22–26.

Putra, M.D., Bláha, M., Wardiatno, Y., Krisanti, M., Yonvitner, Jerikho, R., Kamal, M.M., Mojžišová, M., Bystřický, P.K., Kouba, A., Kalous, L., Petrusek, A. & Patoka, J. 2018. *Procambarus clarkii* (Girard, 1852) and crayfish plague as new threats for biodiversity in Indonesia. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **28**: 1434–1440.

Sacchi, R., Cancian, S., Ghia, D., Fea, G. & Coladonato, A. 2021. Color variation in signal crayfish *Pacifastacus leniusculus*. *Current Zoology*, **67**: 35–43.

Sage, B.L. 1962. Albinism and melanism in birds. *British Birds*, **55**: 201–225.

Schuster, G.A. 2020. Review of crayfish color patterns in the Family Cambaridae (Astacoidea), with discussion of their possible importance. *Zootaxa*, **4577**: 63–98.

Thacker, R.W., Hazlett, B.A., Esman, L.A., Stafford, C.P. & Keller, T. 1993. Color morphs of the crayfish *Orconectes virilis*. *American Midland Naturalist*, **129**: 182.

Tlusty, M. & Hyland, C. 2005. Astaxanthin deposition in the cuticle of juvenile American lobster (*Homarus americanus*): Implications for phenotypic and genotypic coloration. *Marine Biology*, **147**: 113–119.

Usio, N. 2000. Effects of crayfish on leaf processing and invertebrate colonisation of leaves in a headwater stream: Decoupling of a trophic cascade. *Oecologia*, **124**:608–614.

van Grouw, H. 2021. What 's in a name? Nomenclature for colour aberrations in birds reviewed. *Bulletin of the British Ornithologists' Club*, **141**:276–299.

Villalobos, A. 1943. Estudios de los cambarinos Mexicanos. I. Observaciones sobre *Cambarellus montezumae* (Saussure) y algunas de sus formas con descripcion de una subspecie nueva. *Anales del Instituto de Biología*, **14**: 587–611.

Wade, N., Goulter, K.C., Wilson, K.J., Hall, M.R. & Degnan, B.M. 2005. Esterified astaxanthin levels in lobster epithelia correlate with shell colour intensity: Potential role in crustacean shell colour formation. *Comparative Biochemistry and Physiology, B*, **141**: 307–313.

Walker, M.L., Austin, C.M. & Meewan, M. 2000. Evidence for the inheritance of a blue variant of the Australian fresh-water crayfish *Cherax destructor* (Decapoda: Parastacidae) as an autosomal recessive. *Journal of Crustacean Biology*, **20**: 25–30.

Weiperth, A., Blanka, G., Kuříková, P., Bláha, M., Kouba, A. & Patoka, J. 2017. *Cambarellus patzcuarensis* in Hungary: The first dwarf crayfish established outside of North America. *Biologia*, **72**: 1529–1532.

Welch, S.M., & Eversole, A.G. 2006. The occurrence of primary burrowing crayfish in terrestrial habitat. *Biological Conservation*, **130**: 458–464.