UV light as a diagnosis tool for conservation and restoration in natural history collections

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Abstract

The use of ultraviolet light for conservation and restoration in art collections is a common practice. In natural history collections, reaction to UV has been spotted in numerous animal groups; biofluorescence is widespread in the animal kingdom. Here it is the potential of UV light in terms of conservation and restoration of natural history specimens that is explored. UV-induced visible luminescence (UVL) of natural materials are characterized and complemented by actual examples of restored specimens under both regular and UV light. Carpet beetles attack can be spotted due to bright frass, but not other pests and mould in a conclusive way. Restored parts are identified due to glowing inconsistencies. Unusual treatments and dirt may also be distinguishable. It is therefore possible to inspect the integrity and authenticity of specimens, e.g. new acquisitions, and to adapt conservation treatment. As a help to diagnosis, it does not replace the judgement of a conservation specialist.

Keywords: natural history, taxidermy, replicas, conservation, restoration, museum collection, museum specimens, collection management, UV light, fluorescence, luminescence

Introduction

Fluorescence under UV light exposure has been demonstrated in many species across the animal kingdom e.g. invertebrates (Welsh *et al*., 2012; Lagorio *et al*., 2015), fish (Sparks *et al*., 2014), reptiles (Prötzel *et al*., 2018; Gruber and Sparks, 2015), amphibians (Lamb and Davis, 2020), birds (Pearn *et al*., 2001; Dunning *et al*., 2018; Camacho *et al*., 2019), mammals (opossums: Pine *et al*., 1985; flying squirrels: Kohler *et al*., 2019; platypus: Anich *et al*. 2021). Some of these findings were made from museum specimens i.e. taxidermy and study skins (Kohler *et al*., 2019; Anich *et al*. 2021). Research in that field discusses the molecular mechanisms of biofluorescence as well as the evolutionary reasons in terms of adaptation and behaviour. These references are the tip of the iceberg regarding fluorescence in the animal kingdom, and what was considered as an exceptional discovery seems to be widespread. Kohler *et al*. (2019) reports that fluorescent compounds were discovered in bones, feathers, skin, shell and hairs, and emitted colours cover all the visible spectrum except orange.

How can UV light serve conservators and restorers to diagnose specimens they take care of? It is routinely the case in art collections, sometimes in a thorough way; analytical imagery combines complex technologies and computer treatments to transform raw data into exploitable images (Landi and Maino, 2011; Lanteri *et al*., 2019; Webb, 2019). Webb (2019) accurately depicts how

useful UV light is for conservation in art and history museums: characterization and differentiation of materials, state of conservation, identification of past treatments, but also limitations and standardization issues.

Here I want to fill a gap in literature regarding natural history collections that are not specifically taken into account. I present the possibilities offered by UV exposure to help diagnose specimens before implementing conservation or restoration measures and to inspect specimens on loan, subcontracted works and new acquisitions. The following questions underlie the present exploration: What natural materials "glow" under UV light? May UV light help to distinguish original and replica items or parts of them? Can biological attacks, dirt and previous interventions be spotted?

I don't aim to list comprehensively what species react to UV light; by illuminating an entire collection, I want to generalize what conservators and restorers can expect to reveal and hence what is unexpected. These observations are complemented by actual examples that conservators and restorers may encounter.

Material and methods

Ultraviolet rays are invisible and come just after violet. The energy of photons is higher in UV than in the visible light; some materials can absorb this energy and emit lower energy photons among the visible spectrum. This is called fluorescence (Mouchet and Deparis, 2021).

The two wavelengths tested are 375 and 405 nm. The two main commercially available lamps have wavelengths of 365 and 395 nm. Analysis of the spectra (spectroradiometer Apogee model SS-110) reveals that the peaks of emission were slightly different than expected (375 and 405 nm; Figure 1) but results were consistent with preliminary tests using calibrated LED. Ranges of emission include wavelengths used in literature regarding biofluorescence and are the long-wave UV (UVA) used in the field of conservation (Measdey *et al.*, 2017).

The vivid aspect of some materials under UV exposure is not necessarily due to fluorescence in the molecular sense. To avoid any confusion, I use the term "UV-induced visible luminescence" (UVL; Webb, 2019), that groups luminescence (including fluorescence and phosphorescence; Hickey-Friedman, 2002) and total or partial reflectance. Indeed, part of the emitted spectrum of lamps (from 400 nm) belongs to the visible light (Mouchet and Deparis, 2021).

Natural history specimens were inspected and materials divided into different categories: eyes (glass and acrylic), keratinous appendages (beaks, claws, horns, feathers, hairs, etc.), vertebrates skin, bones (including antlers), minerals (shells, bird eggs, fossils and corals), arthropods (insects, arachnids and crustaceans), biological attacks (pests and mould) and fluid collections. I feature what is typically observed without looking for exceptions. Results are given as a guide but not as a rule. Following this goal, characterizing emitted colours is based only on visual perception, consistently

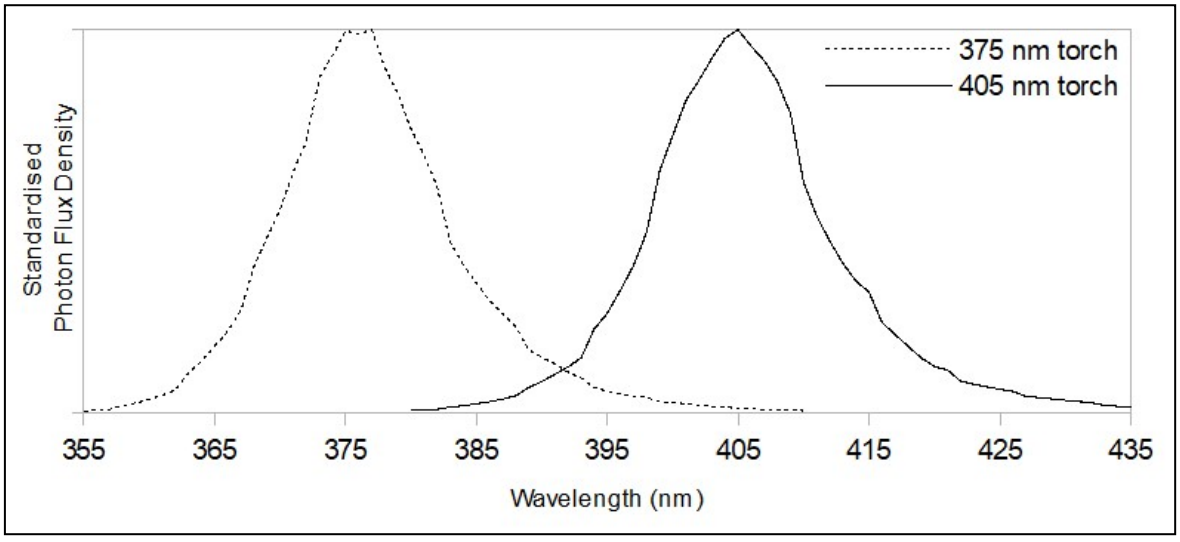

Figure 1. Emission spectra of the two lamps used in the study. Photon Flux Density (in micromoles per square meter per second) was normalized to the maximum value to remove the "intensity" variable that was not specifically controlled.

with previous works, and especially the review of Measdey *et al*., 2017:

- Reactive specimens: yellow, yellow-white and yellow-green (generally light and bright), blue, green and blue-green, purple or violet, red (brownish or purplish), orange, white.
- Non-reactive specimens: black (neither reaction nor reflectance), neutral (no particular reaction observed; only inconsistent reflectance of visible violet wavelengths depending on distance/intensity of the emitting lamp).
- Intensity: more or less bright or dark, milky (diffused).

Investigated specimens come from different museum collections in order to cover all materials. Most were found in the zoological collection of the University of Namur (UNamur), supplemented by the Namur African Museum (MusAfrica) collection for big mammals, the Museum of Zoology of the Free University of Brussels (ULB) for small mammals and a private collection for eggs. It totals more than 5200 specimens or parts of specimens, most of them being shells (1500) and insects (2000). Artificial materials were already investigated in the literature dedicated to conservation and restoration in general (Measdey *et al*., 2017), but paints and artificial eyes have been included because of their omnipresence in natural history collections. Specimens were examined at 405 nm. The 375 nm wavelength showed few interesting/conclusive results.

Photographed specimens display a variety of "inconsistencies" that conservators and restorers could encounter. Considering that it is a tool for everyday use and that we look mainly for surface inconsistencies, standardization is unnecessary. These specimens were photographed under available light (artificial and/or natural) and then under UV light in complete darkness with the same angle of view using a regular triple-camera smartphone. Due to the phone's auto-adjustment settings depending on various light conditions, brightness and contrast may have been edited with GIMP 2.10.8 to achieve a rendering close to reality. The wavelength mainly tested was 405 nm. Some specimens were also inspected at 375 nm. Specimens come from university collections (when specified) and private collections (when unspecified).

Results

Table 1 shows the UV-induced visible luminescence (UVL) at 405 nm of materials found in natural history collections.

Eyes are artificial in taxidermy mounts. Glass and acrylic eyes were tested during this study. Only orange and yellow glass eyes were, in some cases, fluorescent. Some glass eyes are painted at the back so that paint can react independently of glass. Other are neutral. Acrylic eyes glow milky blue or blue-green. Although glass and acrylic resin are currently used to make commercial eyes, other resins, like epoxy, are also used.

Keratin-based materials (dander/appendages or epidermal productions: beaks, bird leg scales, spines, scales, hairs, horns, claws and feather rachis) were reactive when they were light in colour. For darker ones, there was no reaction, and they appeared black or reflect violet, except at the base where they are often lighter and finer. Feathers have particular reactions: some dark plumages glow violet as well as green plumages. One greasy amelanistic raccoon and one greasy wood pigeon rump, both light grey in colour and both recent taxidermy (< 5 years) appeared yellow-green.

The skin of all vertebrate groups also reacted quite vividly. For example, skin around the eyes, nose, mouth and inside of the ear glowed yellow-white, unless the skin was very dark or black (no reaction) or painted (hence appears dark purple). Some birds with black skin (e.g. egrets) were not available but black skin is probably neutral in birds as in mammals. For fish and reptiles, the variety of emission depended on pigmentation: dark parts are neutral while light parts glow yellow-green.

Chitin seemed to react differently between groups: insects and arachnids reacted very little, except for joints, some beetles, butterflies, spider abdomens and light-coloured scorpions. Crustaceans, on the other hand, reacted in more or less dull yellow-green and violet.

Tissue residues were reactive, and this was particularly evident in osteological mounts. Cartilage remnants in joints appeared yellow, while bone varied from white to yellow or violet. Teeth roots were also reactive, but enamel was not, appearing white or reflecting violet.

Shells were fairly neutral on the surface, except for nautiluses and paper nautiluses. The umbilicus and inner surface were reactive. Corals reacted from white to violet. Tested fossils did not fluoresce.

Chicken eggs showed little reactivity at 405 nm, regardless of ground colour and spots. Other species tested were white goose, ostrich, emu, greater rhea, common pheasant, blue tit and great tit, with similar results. In this case, the 375 nm

wavelength had more diverse results than at 405 nm: albumin residues around the blowing holes glowed white, scratches in the pigmented coating and white punctuations stood out, and some brown eggs had areas where UVL was bright (purplish or brownish) red.

Fluid collections glowed green or blue-green, whether the jars were old or new. Only a few old jars from specialist dealers showed no UVL and remained perfectly translucent.

Table 1. UV-induced visible luminescence (UVL) at 405 nm of materials found in natural history collections.

Category	Type	UV-induced visible luminescence	Number of specimens
Eyes	Glass	Neutral. Orange, yellow and white eyes sometimes fluorescent	> 150
	Acrylic	Milky blue or blue-green	> 20
Keratinous appendages	Beaks	Dark parts are neutral, light parts glow yellow-green	> 180
	Claws	Dark parts are neutral, light parts glow yellow-green	> 200
	Horns	Dark parts are neutral, light parts glow yellow-green	13
	Spines and scales (1)	Dark parts are neutral, light parts glow yellow-green	4
	Feathers	Light calamus and rachis generally glow yellow-white while vanes are more or less neutral, dark plumages are generally neutral but some glow dark violet (pigeons, n=11 ; gulls, cormorants, raptors, n=10), green plumages of parakeets glow violet (n=4)	> 180 species
	Hairs (2)	Dark parts are neutral, light parts glow yellow-green, white glows white	20
	Baleens	Dark parts are neutral, light parts glow yellow-green	1
Skin (dried, without paint and varnish)	Mammals	Naked skin glows yellow-green, except when black	20
	Birds	Dark parts are neutral, light parts glow yellow-green (feet and face)	> 180 species
	Reptiles (3)	Dark parts glow (dark) purple, light parts glow yellow-green	14
	Amphibians	Dark parts are neutral, light parts glow yellow-green	1
	Fish and sharks (4)	Dark parts are neutral, light parts glow from white to (yellow-)green	15
Osteology	Bones, skulls and antlers	White, purple and (greenish-)yellow depending on fat and residual tissues	> 100
		Articulations generally glow yellow	
	Enamel	White to purple	> 50
	Teeth plaque and	Purple to black	> 50
	Teeth roots	White, yellow, rarely purple	> 50
	Ivory	White to yellow-green; old yellowed ivory is neutral	4
	Fossil teeth (5)	Neutral	4
Mineral	Shells (bivalves, gasteropods and nautiluses)	No particular glowing, sometimes a bit yellow at ombilic, edges; inside generally white or yellow-green; nautilus and paper nautilus bright at surface ; incrustation of algae or ectoprocta may glow	> 1500 (>450 species)
	Bird eggs (6)	No particular glowing, mat aspect, inner membrane glows white	> 150
	Fossils	Neutral whatever limestone or shale	> 50
	Coral	Yellowish white and violet	34
Arthropods	Insects	Generally neutral, joints often yellow or neutral; some beetles and butterflies glow yellow-green or yellow	> 2000 (all orders)
	Scorpions	Dark ones are neutral (joints sometimes yellow), light ones glow yellow-green	4
	Spiders and amblypygids (7)	Neutral, but joints and abdomen sometimes yellow	23
	Crustaceans (without paint nor varnish) (8)	Yellow-green and violet	10
Biological attacks	Carpet beetle frass	Yellow-green	4
	Moths (larvae, frass, cocoons and adults)	Frass neutral to yellow-green, larvae glow yellow-green but not cocoons and adults	3 degraded specimens
	Booklice frass	Neutral	> 10
	Mould	Neutral	> 10
Fluid specimens	Museum, university and didactical preparations	Milky green or blue-green; 5 ancient development models from professional sellers do not react (UNamur items n°427, 433, 435, 1122, 1124)	> 150

(1) porcupine, hedgehog, echidna, pangolin; (2) raccoon, leopard, wild boar, roe deer, fox, cat, marten, hare, rabbit, buffle, various antelopes; (3) various snakes, lizards, turtles, crocodiles; (4) various percids, salmonids, boxfish, seahorses, sharks; (5) fossil sharks; (6) mostly chicken eggs (from white to dark brown, blue and green, variously spotted from white to dark brown); (7) amblipygids and tarantulas; (8) various crabs and crayfish.

The powdery frass of carpet beetles was easy to spot even on diorama ground as it glowed yellow. For moths, there were no UVLs for cocoons and adults but larvae were very bright, and the droppings varied from neutral to yellow, perhaps depending on the type of the raw material that was nibbled.

Booklice that are found in herbaria and entomological collections typically produce fine powder that is easily spotted without any effort in regular light; UV light only brought more contrast due to white-reflective cardboard, especially at 375 nm. These collections are also subject to mould that doesn't need UV light to be spotted either, but it appeared whiter under 375 nm. Regular dust ("house dust") appeared violet at 405 nm.

Paints (acrylic, watercolour and gouache) were particularly distinctive because they do not react to UV light (except, of course, for fluorescent paints, which are rarely used in this field). Paints therefore appeared very dark, contrasting with the yellow-green or violet of natural materials. They appear dark purple at 405 nm and black at 375 nm. The absence of reaction of paint is essentially what will enable restorations and replicas to be identified. Only the pure red gouache was fluorescent at 375 nm, but of course UVLs may vary among different brands.

Old varnish such as picture varnish was dark yellow-green unlike modern acrylic varnish which is more neutral.

Resins have not been tested because they are very diverse (polyester, epoxy, acrylic and polyurethane) and are often charged to modify texture and colour, making the combinations infinite.

Figures 2 to 9 show specimens under normal and UV light.

Figure 2. ***Upper row.*** *Female gorilla skull from the Maison Tramont on display (UNamur-619). UV light clearly reveals a restoration (arrow) carried out at an undetermined time and had never been spotted before. Examination of the inside of the cranial cavity reveals a round hole, which indicates that the skull must have been base-mounted or once belonged to a complete skeleton. UV at 405 nm.* ***Lower row.*** *Babirusa skull on display (UNamur-602). A missing tooth was replaced by a resin cast of the other one. Under UV light, the roots have different UVLs (arrows). On the right, the two teeth in their entirety: the glowing original (left) and the purple-reflecting replica (right). UV at 405 nm. © Liévin Castelain, 2024.*

Figure 3. Lambis *sp. shell. In visible light, nothing special appears. Under UV light, tips have different UVLs; tips 5 and 6 are original and were cast to restore the other tips in painted plaster resin (1, 2, 3, 4 and 7). UV at 405 nm. © Liévin Castelain, 2024.*

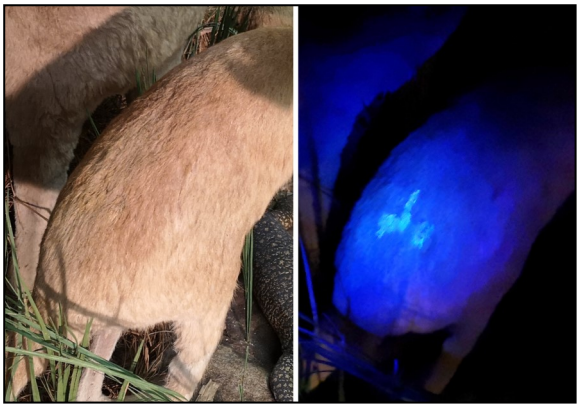

Figure 4. (Above) Kangaroo in a Rowland Ward diorama c1892. Holes in the coat caused by moth attack have been filled with bleached roe deer hair. The inconspicuous restoration is revealed by UV light thanks to the different UVL between the two types of hair. UV at 405 nm. © Liévin Castelain, 2024.

Figure 6. (Right) These two orangutan skulls are virtually identical, but one is actually a replica of the other and the quality of the casting makes it difficult to authenticate the original from the replica. Such a replica could easily be regarded as authentic, or cleaned without caution with solvent. Under UV light, the original skull glows as expected for natural bone, as do the teeth (violet enamel and yellow-green roots) while the polyester resin replica has no UVL and simply reflect violet wavelength. Other resins (e.g. polyurethane) can produce other UVLs closer to bone ones. UV at 405 nm. © Liévin Castelain, 2024.

Figure 5. ***Left column.*** *Tiger from the Center for Scientific Culture, ULB. Top, before restoration. Middle, after restoration. Below, the restoration of the lower canines is clearly visible under UV light. UV at 405 nm.* ***Right column.*** *Mounted whale foetus (Museum of zoology, ULB-RG101A). Top, before restoration. Middle, after restoration; tears and holes of were restored with Japanese paper and painted with watercolour and acrylic paint. Below, location of restored parts are easily identified with UV light. UV at 375 nm. © Liévin Castelain, 2024.*

Figure 7: ***Upper row****. Abnormal illumination of a fox skull indicates that it has been treated differently. Actually this skull has been treated with laundry bleach containing sodium percarbonate and optical brighteners.* ***Middle row.*** *The leg of a kestrel that has been attacked by parasites. Frass is not visible on the rock, but stands out under UV light (arrows). UV light at 375 nm gives a different view, but no clearer than 405 nm. Unpainted parts of toes (underneath) can also be seen, appearing white at 375 nm (right).* ***Lower row.*** *Ratite egg on display (Museum of zoology, ULB-2632). Simply broken at first glance, UV exposure shows that a product has leaked onto the egg. Restoration must be accompanied with appropriate cleaning.* ***Middle column*** *at 405 nm.* ***Right column*** *at 375 nm. © Liévin Castelain, 2024.*

Figure 8. Mounted brown trout. Under UV, the head has a different rendering than the body. In this case the head is artificial and skin and fins are original (and unpainted). Head and body were coated with the same acrylic varnish. UV at 375 nm. © Liévin Castelain, 2024.

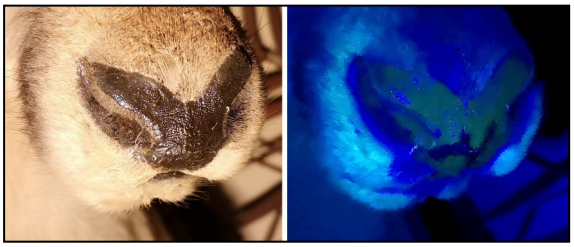

Figure 9. Red kangaroo snout in a Rowland Ward diorama from c1892. The restored tear between nostrils is invisible but the UVL of the restoration looks different than the rest of the nose: original varnish glows dark yellow-green, while restored tear is neutral (acrylic paint and varnish). UV at 405 nm. © Liévin Castelain, 2024.

Discussion

The use of ultraviolet light in art collections has a proven track record (Hickey-Friedman, 2002; Webb, 2019), and its potential is explored here for natural history collections. UV-induced visible luminescence (UVL) has been noted in recent years for various animal groups with molecular and ecological considerations, but it is its use for conservation and restoration purposes that is investigated in the present study.

The reactions observed are in line with what was expected; materials containing keratin, collagen and fat react to ultraviolet light, such as bone, dentine, joints, skin and appendages (Collins, 1992; Bachmann *et al*, 2006; Kollias *et al*., 2002). This is a general summary that should not obscure the fact that fluorophores are very numerous and that identifying their chemical compositions is far from easy (Hughes *et al*., 2022). UVL did not appear to be different for old and recent specimens (except for ivory as noticed by Simpson-Grant, 2000), even though degradation of fluorophores is possible over time ("photochemical damage"; Pearlstein *et al*., 2015) and interactions between molecules are also possible, e.g. lipid oxidation that leads to production of fluorescent proteins (Kikugawa and Beppu, 1987). A few examined specimens were greasy but results suggest that fat stands out at least in recent work and on light hairs and feathers.

Natural materials react very little at 375 nm, giving UVLs in shades of grey, except in a few cases: "normal" dust appeared clearly violet, carpet beetle frass glowed yellow-white, what allows attacks to be spotted at an early stage, and acrylic paint appeared black. Given the absence of visible light in the 375 nm-torch spectrum, there is no light pollution with visible wavelengths close to blue, which gives violet reflection, so the contrast is very sharp and restorations stand out. But this wavelength revealed nothing more than 405 nm.

The reactions of "raw materials" are given as a guide and not as a rule. It is likely that a multitude of exceptions exist, and this is a qualitative evaluation that is not intended to be quantitative. First, the intensity of reflectance and colour varies according to the angle and distance (or intensity) of exposure; white and yellow can tend towards green or violet (for example, enamel appears white or violet). Second, there is a wide range of UVL emission due to the composition, ageing and loading of natural and synthetic materials (Webb, 2019). This is not to mention that commercially available lamps emit on either side of their emission peak (see Materials and Methods) and UV covers a wide spectrum below and between the wavelengths tested. In addition, it is possible that fluorescence occurs at a lower intensity when excitation wavelength is not ideal (Hickey-Friedman, 2002). In short, without reproducible protocols and standardisation of the UV emitting source, it is impossible to produce quantitative studies (Webb, 2019), and it is therefore conceivable that the observed colours and contrasts depend on the equipment. The case of the platypus is illustrative. Anich *et al.* (2021) illuminated specimens with UV light at 385-395 nm, achieving striking results. In the present study, yellow-green UVL was also observed in the platypus, but with much lower intensity. The UV lamp used peaks at 405 nm, meaning it contains a low proportion of 385-395 nm wavelengths, and neither its emitted intensity nor the emitted UVL can be compared with that of Anich *et al.* (2021).

But the quantitative characterisation of UVL is not the central element here; it is a question of differences in reaction, i.e. inconsistencies in UVLs ("surface inconsistencies"; Hickey-Friedman, 2002) because differences in reactions are eye-catching compared to homogeneous reactions. Restored parts stand out and comparison between similar objects give clues if unusual treatment was applied (such a specimen would require special monitoring, or even analysis to detect the presence of a chemical product/residue that could degrade the specimen and contaminate others) or if the specimen is a replica. With this approach, the UV spectrum is useful as a diagnosis tool in natural history collections, as it is in art and history collections (Simpson-Grant, 2000).

Results regarding fossils should be interpreted with caution. In the present study, only a few specimens were tested, all of which were made of shale and limestone. According to Measdey *et al.* (2017), reaction of geological specimens can be highly inconsistent; this is due to the variability of mineral composition that is site-specific (Croft *et al*., 2004). However UV light has already been used to detect restorations and forgeries in palaeontological specimens (Tischlinger and Arratia, 2013), based on the principle of surface inconsistencies.

Conclusion

How can UV light serve conservators and restorers to diagnose specimens they take care of?

The first thing is to detect the presence of pest attacks and other degradations. The dust produced by carpet beetles is clearly visible and different from usual dust. Unfortunately, this is not the case for the other notorious biological attacks with less promising results for booklice and mould. Results for moths are mixed: glowing of frass is inconsistent, cocoons and adults do not react but larvae glow.

The condition also includes the presence of grease, residual tissue and stains. An abnormal reaction may suggest that a substance is present on or in the specimen. UV can help to assess the situation prior to conservation and restoration work. For example, the presence of paint, varnish or artificial parts influences the choice of the treatment. Similarly, the progress and completeness of cleaning can potentially be monitored using UV.

In this respect, newly acquired pieces, whether by purchase, donation or subcontracting, can be examined to determine their condition and integrity; the presence of restorations, non-original elements or fake parts (e.g. bird skull replaced by a copy in a taxidermy mount). In the case of osteological mounts, given the variety of UVL, it is possible to detect whether all the elements originally come from the same specimen, or whether the specimen is composite (a mixture of different specimens).

Examining specimens with UV light does not require costly equipment, is not time-consuming, and allows to spot inconsistencies in the easiest way possible. By revealing the invisible, UV light is presented as a help to diagnosis: the state of conservation, integrity and authenticity are all elements to which conservators and restorers pay attention to. Of course, reactions or lack of reactions and the interpretations that may result from them do not replace but complement the expertise and judgement of an experienced professional.

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References

Anich P.S., Anthony S., Carlson M., Gunnelson A., Kohler A.M., Martin J.G. and Olson E.R. 2021. Biofluorescence in the platypus (*Ornithorhynchus anatinus*). Mammalia, 85(2): 179–181

Bachmann L., Zezell D.M., da Costa Ribeiro A., Gomes L. and Siuiti Ito A. 2006. Fluorescence spectroscopy of biological tissues – A review. Applied Spectroscopy Reviews, 41: 575–590

Camacho C., Negro J.J., Redondo I., Palacios S. and Sáez-Gómez P. 2019. Correlates of individual variation in the porphyrin-based fluorescence of red-necked nightjars (*Caprimulgus ruficollis*). Scientific Reports, 9: 19115

Collins S. 1992. Studies on the natural fluorescence of wool and wool grease. Unpublished Doctoral thesis, City University London, 299p.

Croft D.A., Kaye T and Panko L. 2004. A new method for finding small vertebrate fossils: ultraviolet light at night. Palaeontology, 47(4): 795-800

Dunning J, Diamond A.W., Christmas S.E., Cole E-L., Holberton R.L., Jackson H.J., Kelly K.G., Brown D., Riverai I.R. and Hanley D. 2018. Photoluminescence in the bill of the Atlantic Puffin *Fratercula arctica*. Bird Study, 65(4): 570–573

Gruber D.F. and Sparks J.S. 2015. First Observation of Fluorescence in Marine Turtles. American Museum Novitates, 3845, 7p.

Hickey-Friedman L. 2002. A review of ultra-violet light and examination techniques. Objects Specialty Group Postprints, Volume Nine, 8p.

Hughes B., Bowman J., Stock N.L. and Burness G. 2022. Using mass spectrometry to investigate fluorescent compounds in squirrel fur. PLoS ONE, 17(2): e0257156

Kikugawa K. and Beppu M. 1987. Involvement of lipid oxidation products in the formation of fluorescent and cross-linked proteins. Chemistry and Physics of Lipids, 44(2-4): 277-296

Kohler A.M., Olson E.R., Martin J.G. and Anich P.S. 2019. Ultraviolet fluorescence discovered in New World flying squirrels (*Glaucomys*). Journal of Mammalogy, 100(1): 21–30

Kollias N, Zonios G. and Stamatas G.N. 2002. Fluorescence spectroscopy of skin. Vibrational Spectroscopy, 28: 17-23

Lagorio G.M., Cordon G.B. and Iriel A. 2015. Reviewing the relevance of fluorescence in Biological systems. Photochemical and Photobiological Sciences, 14: 1538-1559

Lamb J.Y. and Davis M.P. 2020. Salamanders and other amphibians are aglow with biofluorescence. Scientific Reports, 10: 2821

Landi M. and Maino G. 2011. Multispectral Imaging and Digital Restoration for Paintings Documentation. Foresti (Eds.): ICIAP 2011, Part II, LNCS 6979, pp. 464–474

Lanteri L., Agresti G. and Pelosi C. 2019. A New Practical Approach for 3D Documentation in Ultraviolet Fluorescence and Infrared Reflectography of Polychromatic Sculptures as Fundamental Step in Restoration. Heritage, 2: 207–215

Measdey D., Walker C. and Pemberton B. 2017. A summary of ultra-violet fluorescent materials relevant to Conservation. Australian Institute for the Conservation of Cultural Materials. National, Newsletter No 137, 13p.

Mouchet S.R. and Deparis O. Natural Photonics and Bioinspiration. Artech House, Norwood, 223p.

Pearlstein E., Hughs M., Mazurek J., McGraw K., Pesme C., Riedler R. and Gleeson M. 2015. Ultraviolet induced visible fluorescence and chemical analysis as tools for examining featherwork. Journal of the American Institute for Conservation, 54(3): 149-167

Pearn, S. M., Bennett A.T. and Cuthill I.C.. 2001. Ultraviolet vision, fluorescence and mate choice in a parrot, the budgerigar *Melopsittacus undulates*. Proceedings of the Royal Society of London, Biological Sciences, 268: 2273–2279

Pine R.H., Rice J.E., Bucher J.E., Tank D.H. and Greenhall A.M. 1985. Labile pigments and fluorescent pelage in didelphid marsupials. Mammalia, 49(2): 249-256

Prötzel D., Hess M., Scherz M.D., Schwager M., van't Padje A. and Glaw F. 2018. Widespread bone-based fluorescence in chameleons. Scientific Reports, 8: 1–9

Simpson-Grant M. 2000. The Use of Ultraviolet Induced Visible-Fluorescence in the Examination of Museum Objects, Part II. *Conserve-O-Gram* 1/10, 4p.

Sparks J.S., Schelly R.C., Smith W.L., Davis M.P., Tchernov D, Pieribone V.A. and Gruber D.F. 2014. The Covert World of Fish Biofluorescence: A Phylogenetically Widespread and Phenotypically Variable Phenomenon. PLoS ONE 9(1): e83259. doi:10.1371/journal.pone.0083259

Tischlinger H. and Arratia G. 2013. Ultraviolet light as a tool for investigating Mesozoic fishes, with a focus on the ichthyofauna of the Solnhofen archipelago. In Arratia G.,Schultze H-P. and Wilson M.V.H. (eds.). Mesozoic Fishes 5 – Global Diversity and Evolution, pp. 549-560

Webb E.K. 2019. UV-induced visible luminescence for conservation documentation. In UV-Vis luminescence imaging techniques, Eds Picollo M., Stols-Witlox M and Fuster-López L., Editorial Universitat Politècnica de València, pp.35-60

Welsh V.L., Van Hooijdonk E., Intrater N., and Vigneron J-P. 2012. Fluorescence in insects. Proceedings of SPIE - The International Society for Optical Engineering. The Nature of Light: Light in Nature IV, 15p.