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Research Article

Effectiveness of fluorescent angling lures on catch outcomes in European perch (*Perca fluviatilis*) under ambient light conditions

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Abstract

Anecdotal reports in angling media suggest that using fluorescent lures may increase catch rates in dim light or at high turbidity. We conducted a controlled angling experiment, comprising 501 30-min experimental fishing trials in three meso- to eutrophic waterbodies and assessed catch rates and sizes of European perch (*Perca fluviatilis*) caught when offered two soft plastic lures (fluorescent vs. nonfluorescent) with similar reflective spectra. We also examined fluorescent properties of a range of market-available lures and modeled the experimental lure's fluorescing effects under natural lake light. Considering the specific light environment of the study waters, the experimental fluorescent lure could get excited by downwelling visible daylight and fluoresce at depths of up to 3 m. Based on a sample catch of 331 perch, and after controlling for interactions with illuminance, cloud cover, water depth and daytime, the fluorescence of the experimental lure did, however, neither affect the catch rate nor the size of perch caught. Lure fluorescence maybe less important than many anglers believe, but further studies in different lake conditions are needed.

Key words: angling, light, lure color, bait, UV

Introduction

Globally, more than 220 million recreational anglers (henceforth anglers for simplicity, Arlinghaus et al. 2019) catch about 47 billion fish per year (Cooke and Cowx 2004). Anglers spend large amounts of time and money on gear, lures and bait (World Bank Group 2012), hoping to increase catch rates or the sizes of the fish they target (Kageyama 1999). A fish will only be caught if it is vulnerable to angling, which is driven by a fish's internal state (e.g., hunger level), the encounter rate of a fish with the hook, the selective properties of the angling gear used (e.g., lure size in relation to fish and gape size) and lastly the abiotic and biotic environment, which acts upon all these factors (Stoner 2004; Lennox et al. 2017).

Probably the most important gear component that is under control of the angler is the lure which the individual fish must be willing and able to ingest or attack (Lennox et al. 2017). Among other factors (reviewed in Stoner 2004; Lennox et al. 2017), the lure/bait choice is known to influence catch rates and sizes of fish in the catch (e.g., Beukema 1970; Wilde et al. 2003; Cooke and Suski 2004; Arlinghaus et al. 2008; Alós et al. 2009; Stålhammar et al. 2014; Arlinghaus et al. 2017*a*; Bursell and Arlinghaus 2018; Nieman et al. 2020; Lucas et al. 2023; Yoshiyama et al. 2023). Artificial lures common in predator fishing come in a variety of shapes, sizes, movement patterns and colors, offering angler a large diversity of choices to maximize catch outcomes that are desired and generate satisfaction (Birdsong et al. 2021). However, fish can learn to avoid capture by recreational angling gear, especially after being caught and released (e.g., Beukema 1970; Mourier et al. 2017; Czapla et al. 2023; Lucas et al. 2023; Roser et al. 2025). To counteract an angling-induced timidity syndrome (defined as reduced vulnerability to capture after previous encounters with angling gear;

Arlinghaus et al. 2017*b*), constantly novel lure types are designed by the angling industry to attract both anglers and fish.

One factor, supposed by many anglers to make an important difference in catch rates, is the hue (i.e., spectral color) or the perceived color of the lure. Popular angling media is replete with anecdotal reports that specific lure colors affect catch outcomes (Beyer 2018; Brozowski 2018; Flukemaster 2018). Scientifically, the question is poorly studied, and the few available studies that have looked at systematic color effects in artificial lures in predator fishing reported mixed findings and interaction of lure colors with environmental conditions (e.g., Hsieh et al. 2001; Wilde et al. 2003; Moraga et al. 2015; Nieman et al. 2020; Afonso et al. 2021; Ajik et al. 2023). The abiotic environment, including time of the day, light level, water turbidity, temperature, wind speed, and the lunar cycle can all affect catch rates in angling (Stoner 2004; Kuparinen et al. 2010; Lennox et al. 2017), either by moderating habitat choice and state of the fish, or by interactively affecting the responsiveness of fish to certain lure colors through impacts on water coloration and visibility (Nieman et al. 2020).

In recent years, the use of fluorescent lure types, in angler communities commonly labeled as "UV lures", is gaining large attention among anglers. Fluorescence is the absorption of photons at a specific wavelength (excitation wavelength) by a fluorophore, followed by the re-emission at a longer wavelength (emission wavelength) (Marshall and Johnsen 2017; Box 1). Fluorescent lures are called "UV lures" by some anglers and lure distributors (Beyer 2018; Fox Rage TV 2018; Norff 2020), due to the assumption that the excitation wavelengths of these lure types lie within the ultra-violet range (UV, wavelength range: 100–400 nm; ISO 2007). Yet, the range of excitation wavelengths of fluorescent lures available in fishing tackle stores have not been assessed scientifically, and it remains to be seen whether such lure hues are truly excited by UV radiation. If so, fluorescence of lures might indeed affect the consciousness or contrast of the lure when excited by the light spectrum that can penetrate to the water depth where the lure is offered.

Some anglers assume that fluorescent lures lead to higher catch rates compared to standard lures with hues that exclusively rely on reflection particularly in turbid water, deeper water, or under dim daylight conditions, caused by cloud cover or during dusk or dawn (OTW Staff 2013; Beyer 2018; Fox Rage TV 2018). In popular angling media, the higher catch rate is attributed to the increased conspicuousness of fluorescent lure types under these "low visibility" abiotic conditions (OTW Staff 2013; Beyer 2018; Fox Rage TV 2018). However, especially in fresh waters with high dissolved organic compounds and particulate organic and inorganic matter, UV wavelengths are generally strongly attenuated and rarely penetrate into deeper water strata (Arts et al. 2000; De Lange 2000). By contrast, other wavelengths of the (human) visible spectrum, e.g., in the blue–green or green–red spectrum often penetrate deeper into the water (Solonenko and Mobley 2015; Dodds and Whiles 2019; Jechow and Hölker 2019). Therefore if "UV lures" also show fluorescence at these wavelengths, their conspicuousness to fish might indeed increase. Multiple studies indicate a preference of fishes for conspicuous prey (Curio 1976; Bakker et al. 1997), and some experiments have indeed revealed also a preference for fluorescent prey (Hill et al. 2011; Haddock and Dunn 2015) or even a preference for prey that emits UV wavelengths (Khan et al. 2023). Therefore, if fluorescence of a lure increases its conspicuousness it could in turn increase the vulnerability of a fish targeted by an angler and thus indeed positively affect catch rates (Curio 1976; Lennox et al. 2017).

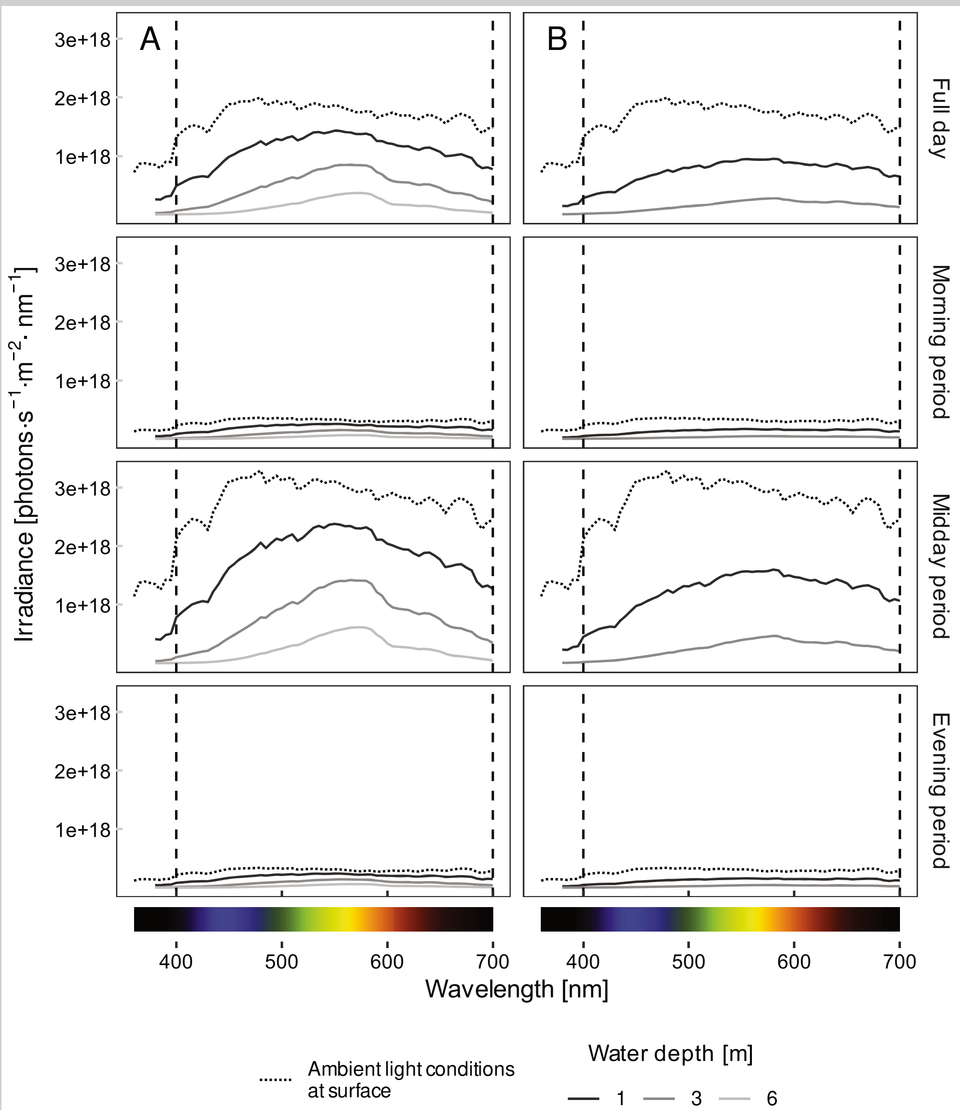
Increased conspicuousness and fluorescence visible to the fish requires that excitation wavelengths are available in the environment where the lure is offered, which depends on water depth, turbidity, and generally light conditions (Box 1; Sandström 1999; Dring et al. 2001). Importantly, the perceived contrast between light reflection and fluorescence of an object may be more pronounced at lower total irradiance, for example at dusk or dawn, or under dense cloud cover (Hecht 1924; Land and Nilsson 2012). This may indeed cause fluorescent lures to be particularly conspicuous during dusk and dawn. Colors produced by light reflection alone lose their detectability for fishes with decreasing illuminance (Vogel and Beauchamp 1999; Hansen et al. 2013). Therefore, nonfluorescent lures might have a decreased catch rate with decreasing illuminance, while fluorescent lures could slow down this effect. This is because the emitted light can make fluorescent objects appear brighter and more conspicuous due to e.g., their isotropic emission and by absorbing common wavelengths at a specific depth and re-emitting uncommon or absent wavelengths (Marshall and Johnsen 2017). However, it remains untested whether using fluorescent lures commonly sold in tackle shops can indeed increase catch rates in the wild.

This study offers a baseline for the description of the fluorescent properties of a selected set of so-called "UV lures" sold to anglers; it aims at improving our understanding about the role such fluorescent lures might play in the angling of European perch (*Perca fluviatilis*, perch hereafter) as a model species. The study followed two steps: (1) selected fluorescent lures of different types/brands used by anglers were characterized regarding their fluorescent excitation and emission properties under standardized laboratory conditions to facilitate a discussion of their potential visibility in different environmental settings in fresh waters; and (2) using an angling-based field study, differences in catch per unit effort (CPUE) and length of caught perch between lures of differing fluorescence property were tested, while controlling for environmental covariates, especially those related to light conditions underwater. We predicted that the perch CPUE of a specific fluorescent lure (KEITECH® Easy Shiner) used as a model in this study would be higher than that of a comparable nonfluorescent lure of the same brand. Furthermore, we predicted that any increase in CPUE for the studied fluorescent lure would be more pronounced under conditions of lower light, such as at dusk and dawn, under cloud cover, or at greater angling depths, relative to the studied nonfluorescent lure.

Box 1. Fluorescence and light environment in meso- to eutrophic waters.

The fluorescent effects of lures can only be expressed when their fluorophores are excited by downwelling light in the environment. Water acts as an optical filter, altering the spectrum and intensity of light (Jechow and Hölker 2019; Kühne et al. 2021; Hölker et al. 2023), with attenuation influenced by absorption and scattering from water and its constituents, such as organic material, particles, and dissolved compounds (Dodds and Whiles 2019). Attenuation is strongly wavelength-dependent: in clear, oligotrophic waters, UV radiation (300–400 nm) and purple–blue light (400–500 nm) reach deeper than red light (600–700 nm), whereas in turbid, moderately to highly eutrophic waters as is typical for many European fresh waters (European Commission 2021), shorter wavelengths are absorbed more rapidly (Solonenko and Mobley 2015; Dodds and Whiles 2019), limiting the excitation of fluorescent lures even at shallow depths. An example from a weakly eutrophic waterbody near Berlin, Germany, which also served as a study site for our angling experiments, is shown in Fig. B1. Underwater light was modeled from spectral attenuation coefficients measured from water samples taken at different depths (see Materials and methods, Table S1). Assuming absorption to dominate scattering, only a small fraction of the incoming irradiance, and even less in the UV/blue spectrum, could be transmitted to the lure, excite the fluorophores and can subsequently be re-emitted to the predator's eye (Fig. B1). For example, the relative intensity of the UV (∼380 nm) and visible blue spectrum (∼450 nm) of incoming light at the water surface that can reach a depth of 3 m was only 3% and 14%, respectively. Given absorbance and additional scattering in natural environments, UV/blue light becomes exceedingly scarce at greater depths of such eutrophic waters. Consequently, fluorescence lures with excitation wavelengths below the blue spectral range (<500 nm) would only fluoresce in much clearer water or at very shallow depths. In addition, there are natural turbidity thresholds at which all wavelengths are strongly attenuated within less than a meter (Dodds and Whiles 2019). Obviously, neither reflection nor fluorescence can improve a lure's optical appearance when no light is present, e.g., at night, in very turbid water or at great depths.

Fig. B1. Ambient spectral irradiance at the surface and for specific water depths of a mesotrophic (A) and weakly eutrophic (B) study waterbody. Single rows represent downwelling depth-specific light environments for an average day and for three daytime periods. Spectral attenuation was inferred from wavelength-specific absorption coefficients, not accounting for light scattering. Local spectral irradiance at the surface was obtained from Farias-Basulto et al. (2023).



Materials and methods

Fluorescence characteristics of market-available fluorescent-labeled lures

To analyze whether artificial lures ($n = 16$) for predator fishing in fresh waters offered to German anglers and considered as fluorescent are excited by UV radiation and other wavelengths, standardized laboratory measurements were performed. Lures of several popular manufacturers commonly available in German angling stores were randomly bought from a tackle shop in Berlin and tested for their fluorescent appearance when illuminated with a commercially available narrow-band, UV-emitting (395 nm) flashlight in the shop, a method commonly used by anglers. The selected fluorescent lures comprised soft plastic baits (e.g., shads, craws; $n = 10$) and metal, plastic, and wooden hard baits (e.g., spinners, wobblers, crankbaits, swimbaits; $n = 6$). Standardized fluorescence measurements were then conducted with a fluorescence spectrometer (PerkinElmer® FL 6500) by creating a monochromatic light beam (tunable from 320 to 749 nm in 5 nm intervals) incident on a lure. Quantifying the fluorescence emitted by the lures was done by detecting the spectral radiance from 360 to 855 nm in 5 nm intervals. Plotting the emitted radiance along the excitation versus emission wavelength spectrum (excitation × emission matrix) was used to describe the main fluorescent properties of the lures. Furthermore, the peak excitation wavelength of the fluorescence, i.e., the wavelength of the excitation beam at which the emitted radiance was highest, was determined for each lure. This identified the specific wavelength that primarily excited the lure's fluorophores. Subsequently, it was categorized whether the peak excitation wavelength for a given lure falls within the UV range (100–400 nm) or beyond in the blue–green–red spectrum (>400 nm). Some of the lures examined considered the experimental lures used in an angling-experiment (see below).

Study area and waterbody-specific light environments

The angling trials were conducted at three meso- to weakly eutrophic waterbodies near Berlin (Germany) with total phosphorus concentrations during the study between 0.04 and 0.09 mg·L^{-1}. Secchi depths in the waterbodies ranged between 2.9 and 4 m. Average water depths of the study waterbodies was between 3 and 5.8 m. In all study waters perch is a common predatory species, which is a popular target for recreational angling in Germany (Arlinghaus and Mehner 2004; Heermann et al. 2013).

Relative spectral irradiance at specific depths of two of the three study waterbodies was calculated using depth-specific spectral absorption coefficients (Dodds and Whiles 2019). Absorption coefficients ($\eta_{z,\lambda}$) were measured with a flow-through point-source integrating cavity absorption meter (ft-PSICAM, Trios OSCAR) from water samples collected in June (waterbody A, at depths of 1, 2, 3, 4, 5, and 6 m) and July (waterbody B, depth of 1 m), respectively. From $\eta_{z,\lambda}$ we modeled the relative downwelling irradiance of a given wavelength (assuming no strong wavelength-specific scattering effects) that reaches a specific depth (Fig. S1, Table S1):

$$I_{2\lambda} = I_{1\lambda} \times e^{-\eta_\lambda (z_1 - z_2)}$$

where $I_{1\lambda}$ is the relative irradiance for a specific wavelength λ at depth z_1, η_λ is the wavelength-specific absorption coefficient, and $I_{2\lambda}$ is the relative irradiance at depth z_2. To estimate absolute spectral irradiance at a given depth, we used a solar spectrum dataset measured on ground in Berlin (Farias-Basulto et al. 2023). The dataset provided spectrally resolved solar irradiance (300–1100 nm) at a 35° solar angle with 5 min intervals. From this, we calculated mean spectral irradiance for an average day and for three daytime periods: morning (±2 h from sunrise), midday (2 h after sunrise to 2 h before sunset), and evening (±2 h from sunset). Sunrise and sunset times for the measurement location (52.431°N, 13.524°E) were determined using the R package "activity" (Rowcliffe 2023).

Spectral irradiance values in power units (W·m^{-2}·nm^{-1}) were converted to photon irradiance (photons·m^{-2}·s^{-1}·nm^{-1}) by multiplying the value by the wavelength in nm and by 5.05×10^{15} at each wavelength (Johnsen 2012; Bitton et al. 2017). Photon irradiance values were then multiplied by the waterbody-specific relative spectral irradiance factors to account for attenuation effects at certain wavelengths, resulting in waterbody- and depth-specific estimates of the spectral photon irradiance. This represents the downwelling wavelength-specific light environment available at a given depth for reflection by an angling lure and excitation of fluorophores in the lure.

To integrate the ambient spectral environment with the lure's optical properties, we combined the depth-specific spectral photon irradiance data with the reflectance and fluorescence characteristics of the fluorescent and nonfluorescent lure used in the angling trials (see below). This involved applying the depth-specific spectral photon irradiance values to the relative excitation × emission efficiency matrix for two used lure types. The excitation × emission matrices, initially measured as radiance in arbitrary units (ignoring scattering effects, focusing solely on fluorescence and reflectance), were normalized to relative radiance matrices by dividing each radiance value by the maximum measured emission radiance for each lure. This procedure allowed us to infer the relative contribution of fluorescence and reflectance to the total spectral emission from the lures under ambient light environments in the study lake at different depths.

Field-based angling trials with fluorescent and nonfluorescent lures

Scientific angling with rod and reel was used to assess the effect of lure fluorescence on catching of perch. Perch can perceive wavelengths in the green to red spectral range (Jokela-Määttä et al. 2019), thus also the fluorescence-emitted (peak at 505 nm) and reflected wavelengths (peak at 675 nm) of the fluorescent lure used in this experiment (see below). Perch is a species that is often targeted with artificial lures by European anglers (Arlinghaus and Mehner 2004; Vainikka et al. 2012; Heermann et al. 2013), and therefore represents an appropriate study species for testing catch effects of fluorescent lures.

Angling took place from shore as well as from boats for 29 days from May until September with in total seven people participating. Each angling day was separated into three daytime periods (1) the morning period starting 2 h before sunrise and ending 2 h thereafter; (2) the evening period starting 2 h before sunset and ending 2 h thereafter, and (3) the midday period starting 2 h after sunrise and ending 2 h before sunset. Sunrise and sunset were calculated for the sampling location for each day at which angling was conducted (Teets 2003) using the R-package "activity" (Rowcliffe 2023). In total 501 angling trials of 30 min each over all waterbodies and all involved anglers were conducted, mostly during midday periods ($n = 246$ trials) followed by evening ($n = 153$ trials) and morning periods ($n = 102$ trials). Each angler was considered an independent sampler. All participating anglers were from the laboratory of the senior author and experienced recreational perch anglers familiar with the local waterbodies; none of the fieldwork was conducted by the first author responsible for data analysis.

During each angling trial, a soft plastic lure (KEITECH® Easy Shiner, http://www.keitech.co.jp) of two different types, a fluorescent (brand name: Motoroil) and a nonfluorescent type (brand name: Red Crawdad) was used (Fig. 1). Before the trials, the fluorescent and reflective properties of one individual Easy Shiner lure of each type ($n = 5$ measurements per lure with different positioning) were analyzed using a fluorescence spectrometer (PerkinElmer® FL 6500) in the laboratory. Fluorescence and reflection radiance was determined with monochromatic excitation light beams ranging from 220 to 800 nm and with detection emission wavelengths from 230 to 800 nm. Fluorescence was defined as emissions at wavelengths greater than the excitation wavelength (±10 nm measurement tolerance), while reflection was defined as emission at wavelengths equal to the wavelength of the incoming light beam (±10 nm). For both lure types, the full reflection spectrum was measured to identify potential differences among lures, which could influence the catch rates (Nieman et al. 2020) and obscure the effect of fluorescence. For analysis, the mean reflection and fluorescence emission (and corresponding standard deviation, SD) for each emission wavelength over the five lure measurements of each type were calculated and visually compared (Fig. 1).

The fluorescent and nonfluorescent lure were fished simultaneously by each angler and for each 30 min session using a drop-shot style fishing rig (Fig. S2). By offering the two types simultaneously, we assumed to generate an equal probability of attracting fish at each cast. The lures were equipped with DECOY® offset-hooks size 1 and mounted with steel wires to avoid losing pike (*Esox lucius*) that might attack the lure as bycatch. The specific lure size, either small (5.4 cm, 2 in.) or large (7.2 cm, 3 in.), and the weight of the lead sinkers (ranging between 5 and 10 g), was freely chosen by the anglers to allow anglers to adapt the weight to wind and water depth. However, the rig had to be equipped with lures of the same size during a single trial. The rig was fished by casting it, allowing it to sink and then retrieving it slowly back to the angler. The fishing style was usually based on very slow retrieval and slow jumps, always keeping the lure close to the bottom. Anglers could animate the lure with occasional rod lifts or let the lures rest in one place for short periods, which was left to the decision of the angler. To prevent any influence of vertical lure position, the placement of fluorescent and nonfluorescent lure (i.e., which lure type was fished on top or bottom of the rig, Fig. S2) was randomly assigned for the first trial by a coin flip at the beginning of the fishing period. Afterwards, anglers swapped the position of the lure types at the beginning of each new 30 min trial. Anglers were allowed to change fishing spots continuously throughout the trials. Because boat-based angling (two waterbodies) and shore-based angling (one waterbody) were spatially confounded with the respective waterbodies, the effects of angling mode could not be disentangled and were statistically accounted for by including waterbody ID (see below).

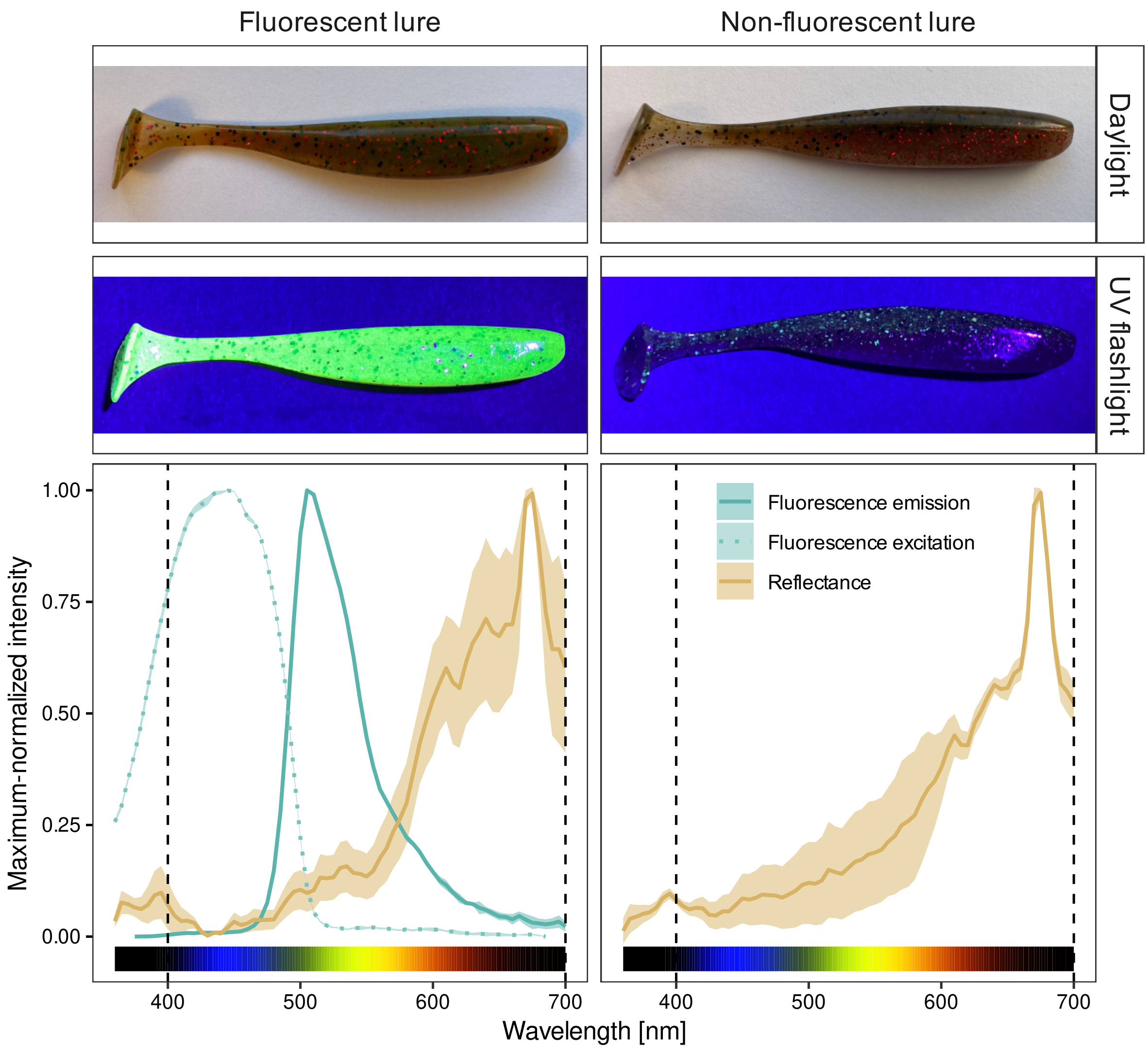
Whenever a fish was caught, the species, individual total length (mm), the taken lure type (fluorescent vs. nonfluorescent) and its position on the fishing rig (top vs. bottom) as well as the hooking depth (shallow vs. deep; see supporting information) were recorded. Subsequent analyses exclusively focused on perch captures; occasional captures of other species ($n = 1$ catfish *Silurus glanis*, 58 northern pike, 4 round goby *Neogobius melanostomus*) were excluded from the dataset. Catch rates were quantified as CPUE (individual perch per 30 min) for each trial separately.

Environmental variables considered to affect light availability underwater, and thus the potential effectiveness of fluorescent versus nonfluorescent lures, were collected in the field for each 30 min session, comprising: cloud cover (%), water depth (m), and illuminance at the water surface (in lx). Depth and cloud cover were estimated as averages over the duration of a 30 min trial by the anglers. Mean illuminance during a trial was calculated using a continuously logging illuminance meter (30 measurements per trial, Extech® HD450). Water turbidity (Secchi depth) was not measured consistently in all study waters and thus not considered in further analysis. In addition to 30 min trial-averages of environmental variables, water depth, cloud cover, and illuminance were also recorded at capture of each individual fish.

Statistical analysis

Effects of the lure type (fluorescent vs. nonfluorescent) were analyzed with regard to perch catch rates and length of caught perch, using generalized linear mixed models (GLMM). GLMMs were fitted with perch CPUE (individuals per 30 min, Poisson distributed GLMM) and total body length of caught perch (Gamma distributed GLMM) as response variables, respectively. An additional GLMM (binomial) with hooking depth as response variable was also fitted (see supporting information). All GLMMs were fitted with lure type, lure size (small vs. large), rig position of the fluorescence lure (top vs. bottom), daytime period, and the environmental variables illuminance, cloud cover, and water depth as fixed effects. Additionally, also interaction terms of lure type with daytime, illuminance, cloud cover, and water depth were included to test for relevance of fluorescence depending on light environment. GLMMs were fitted with random

Fig. 1. Visual appearance and reflectance and fluorescence properties of the fluorescent (left) and the nonfluorescent "Easy Shiner" lure (right) used in the angling trials. Images of the lures show their appearance under daylight and under illumination with a commercially available narrow-band, ultra-violet (UV)-emitting (395 nm) flashlight. Lines in the lower panels provide mean maximum-normalized emissions over five measurements of each lure. Color shaded bands represent corresponding standard deviations. Peak fluorescence of the fluorescent lure was achieved at 445 nm excitation wavelength and 505 nm emission wavelength. Peak reflectance was achieved in both lure types beyond the red spectrum at 675 nm. Bottom color scale shows how a given wavelength would be perceived by the average human eye (Stockman and Sharpe 1999). Dashed vertical lines indicate the boundary of the human visible spectrum (400–700 nm).



intercepts for each waterbody (also covering angling mode boat-based vs. shore-based), angler identity (ID) and calendar month to account for site-specific/angling mode-specific effects, differences in angler skills and monthly effects that were not specifically measured.

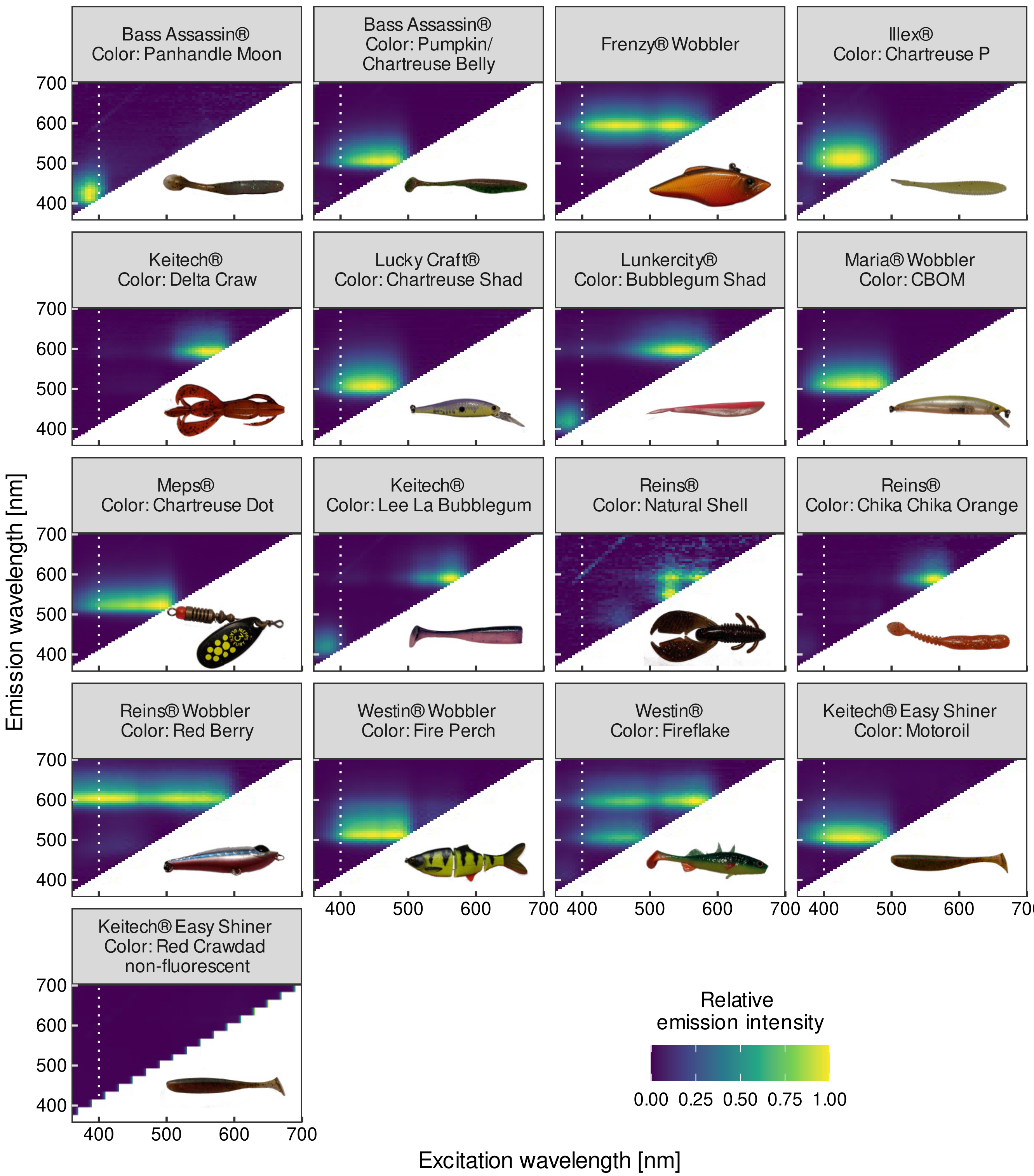
GLMMs were computed using the R package "glmmTMB" (Brooks et al. 2017, version 1.1.9). Model residuals were checked by Q–Q plots with the R package "DHARMa" (Hartig 2022, version 0.4.6). Prior to model fitting, continuous covariates were centered to facilitate interpretation of model coefficients of input variables involved in interactions (Schielzeth 2010). Parametric bootstrapping (function "bootMer" of the R package "lme4," version 1.1-35.3) of each model was used to obtain the 95% confidence intervals (CI, percentile method) of its parameter estimates. Interactions of continuous and categorical predictor variables were visualized with the R-package "emmeans" (Lenth 2024, version 1.10.1). Statistical analyses were performed in R (version 4.4.1) considering an alpha level of 0.05.

Results

Fluorescence and reflection properties of lures

The mean excitation wavelength at which the highest fluorescence was recorded among the sixteen tested fluorescent lures was in the blue–green spectrum at 493 nm ± 64 nm (mean ± SD, n = 16, Fig. 2). Excitation spectra var-

Fig. 2. Wavelength resolved radiance of the fluorescence (*y*-axis) plotted against excitation wavelength (*x*-axis) of sixteen fluorescent lures and one nonfluorescent lure. Emission wavelengths which were 10 nm lower than the excitation wavelength, as well as reflectance emissions were excluded from the plots. Fluorescence radiance was maximum-normalized to the range [0, 1] within each lure. Wavelength resolution was 5 nm for both excitation and fluorescence. Vertical dotted line indicates boundary of the ultra-violet range at an excitation wavelength of 400 nm. Note: the last panels show the fluorescence properties of the two Easy Shiner lures used in comparative angling field-experiment, a fluorescent (color: Motoroil) and a nonfluorescent type (color: Red Crawdad).



ied among the tested lures with excitation wavelengths ranging between roughly 350 (UV) and 600 nm (yellow–red) and peak excitation from 385 to 570 nm (Fig. 3). Also, the fluorescence emission wavelength spectra varied among lures within the visible spectral range (400–740 nm, violet to red, Figs. 2 and 3). Emission wavelengths of highest emission radiance (peak emission) ranged between 415 and 606 nm (mean = 547 ± 55.2 nm, Fig. 3). One tested lure was maximally excited within the UV range (Bass Assassin®, color: "Panhandle Moon"; peak excitation at 385 nm and a corresponding emission peak at 415 nm). A second lure had the peak excitation at the boundary from UV to the visible spectral range (Reins® wobbler, color: "Red Berry"; peak excitation at 400 nm and a corresponding emission peak at 605 nm) (Fig. 2).

The fluorophores of the fluorescent "Easy Shiner" lure that was used in subsequent angling trials were excited by a wide range of wavelengths starting close to the UV range and ending in the cyan spectral range (Figs. 1 and 3). The excitation wavelength with maximum fluorescence of this lure was achieved in the blue spectrum at 445 nm. The emission range of the fluorescent "Easy Shiner" lure ranged from the cyan spectral range to a comparably weak emission in the orange range, with the highest fluorescence being achieved in the green spectrum at an emission wavelength of 505 nm (Figs. 1 and 3). By contrast, the nonfluorescent "Easy Shiner" lure did not show any fluorescent properties in the excitation wavelength range between 360 and 700 nm (Fig. 1). The reflection characteristics of the fluorescent and the nonfluorescent "Easy Shiner" were comparable with highest reflection radiance slightly beyond the red spectral range at 675 nm (Fig. 1).

Considering the ambient spectral irradiance beneath the water surface (Box 1 and Fig. B1) and the fluorescence properties of the experimental lure used in our study (see Materials and Methods, Fig. 1), which was excited in the blue spectral range (~445 nm), our results demonstrate that the experimental lures could have generally exhibited fluorescence effects underwater in the study waters. However, the excitation wavelengths were only available in the top water layers of the studied meso- to eutrophic systems at daylight, producing fluorescence effects down to approximately 3 m or less (Fig. 4). Consequently, under otherwise optimal conditions (e.g., no scattering and no contrast effects), the maximum reflectance emission of both lure types underwater occurred in the red spectrum and beyond (~675 nm) across all water depths. Additional fluorescence emission of the fluorescent lure may have been achieved in the green spectrum (500–570 nm), but only in the uppermost water layers (Fig. 4). But generally, this analysis indicated that the consciousness of the fluorescent lure used should have been more pronounced, as most experimental fishing happened in shallow water (93% of catches at ≤3 m water depth).

Field-based angling trials with fluorescent and nonfluorescent lures

A total of 331 European perch were caught in 501 30 min angling trials. Thereof, 145 individuals (44%) were caught on the fluorescent lure and 186 individuals (56%) on the nonfluorescent lure. The GLMM revealed that lure type (fluorescent vs. nonfluorescent) did not significantly affect perch CPUE ($p = 0.086$, Table 1). More specifically, the fluorescent lure tended to be associated with a slightly lower (although not statistically significant) catch rate compared to the nonfluorescent lure (0.19 ± 0.08 fish/30 min vs. 0.24 ± 0.10 fish/30 min, model-predicted marginal mean ± standard error, Fig. 5). Among the variables considered, illuminance at the water surface, percentage of cloud cover, water depth, lure size, and lure position significantly affected perch CPUE (Table 1). An increase in illuminance and cloud cover, as well as a decrease in water depth, were associated with significant increases in perch catch rates ($p < 0.05$, Table 1, Fig. 5). Using the smaller lure (5.4 cm) resulted in significantly greater catch rates (0.27 ± 0.11 fish/30 min, approximately + 50%) compared to using larger lures (7.2 cm, 0.17 ± 0.07 fish/30 min, $p < 0.05$). Lures positioned at the bottom of the fishing rig yielded significantly higher CPUE (0.25 ± 0.10 fish/30 min) than those positioned at the top (0.18 ± 0.08 fish/30 min, $p < 0.05$; Fig. 5). Daytime did not significantly affect perch catch rates ($p > 0.05$, Table 1).

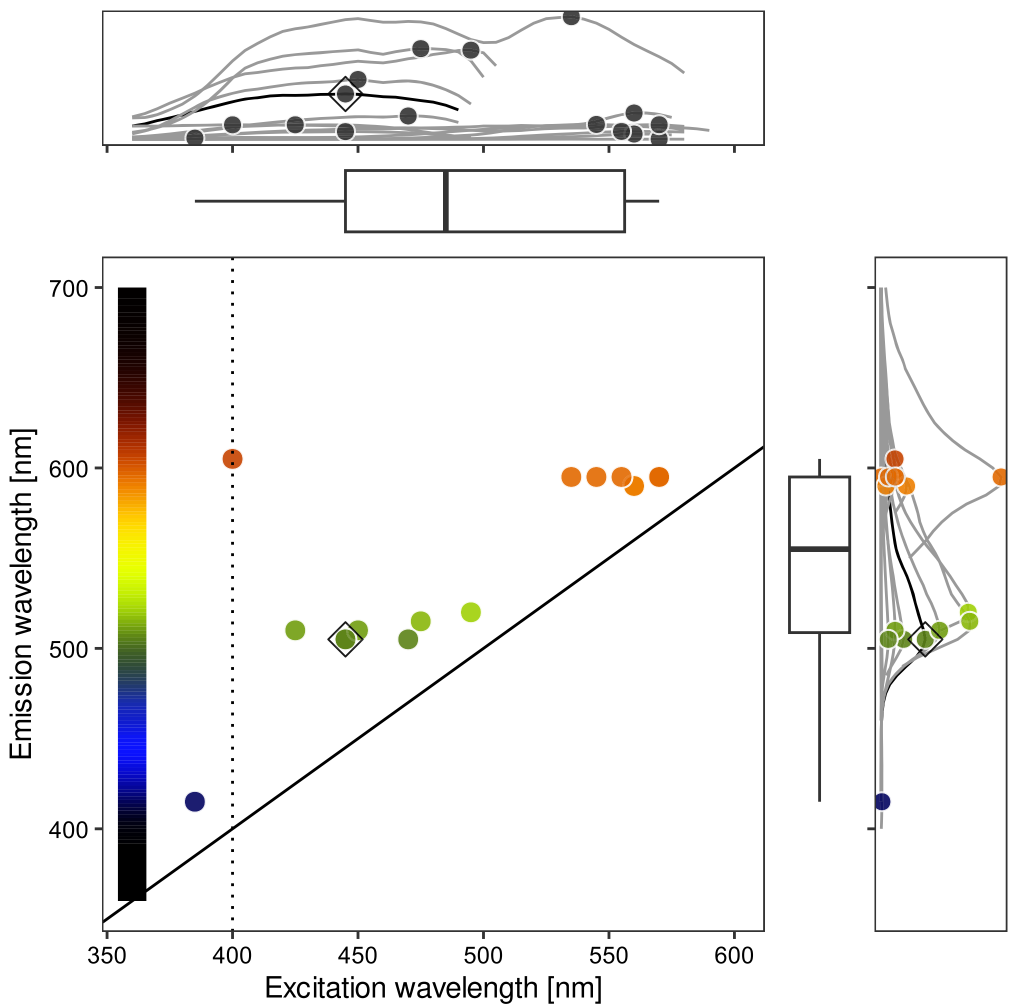
The effects of lure type (fluorescent vs. nonfluorescent) on perch CPUE in interaction with other environmental predictor variables, were not significant (Table 1, Figs. S3.1 and S3.2). During midday, both lure types achieved similar catch rates (fluorescent: 0.24 ± 0.11 fish/30 min; nonfluorescent: 0.23 ± 0.10 fish/30 min; Fig. S3.1). During dim daytime periods, the catch rates for the fluorescent lure appeared lower (morning: 0.14 ± 0.06 fish/30 min, evening: 0.20 ± 0.09 fish/30 min) compared to the nonfluorescent lure (morning: 0.23 ± 0.10 fish/30 min, evening: 0.28 ± 0.12 fish/30 min, Fig. S3.1). However, the interaction effects of daytime period and lure type were not significant ($p > 0.05$, Table 1). Additionally, changes in illuminance or cloud cover did not lead to significant differences in catch rates between the two lure types, nor did changes in water depth (Fig. S3.2, Table 1).

Body length of caught perch ranged between 77 and 410 mm (mean = 186 mm; interquartile range = 133–216 mm) and was not significantly related to the lure type, daytime period, illuminance or cloud cover (Table 1). Estimated length differences of perch caught by the fluorescence lure (191 ± 17.2 mm, mean ± standard error) compared to the nonfluorescent lure (202 ± 18.2 mm) were statistically insignificant. With increasing water depth the lengths of angled perch increased significantly ($p = 0.006$). For example, perch angled in shallow areas (0.5 m water depth) were smaller (173 ± 16.1 mm) compared to deeper (4.5 m) waters (246 ± 25.4 mm, Fig. S4). Interactions of lure type (fluorescent vs. nonfluorescent) with environmental predictor variables, did not significantly affect length of caught perch (Table 1, Fig. S5.1 and Fig. S5.2). Neither the main effects of lure type (fluorescent vs. nonfluorescent) on hooking depth of captured perch nor the interaction effects of lure type with other environmental predictor variables on hooking depth, were significant (Table S6.1).

Discussion

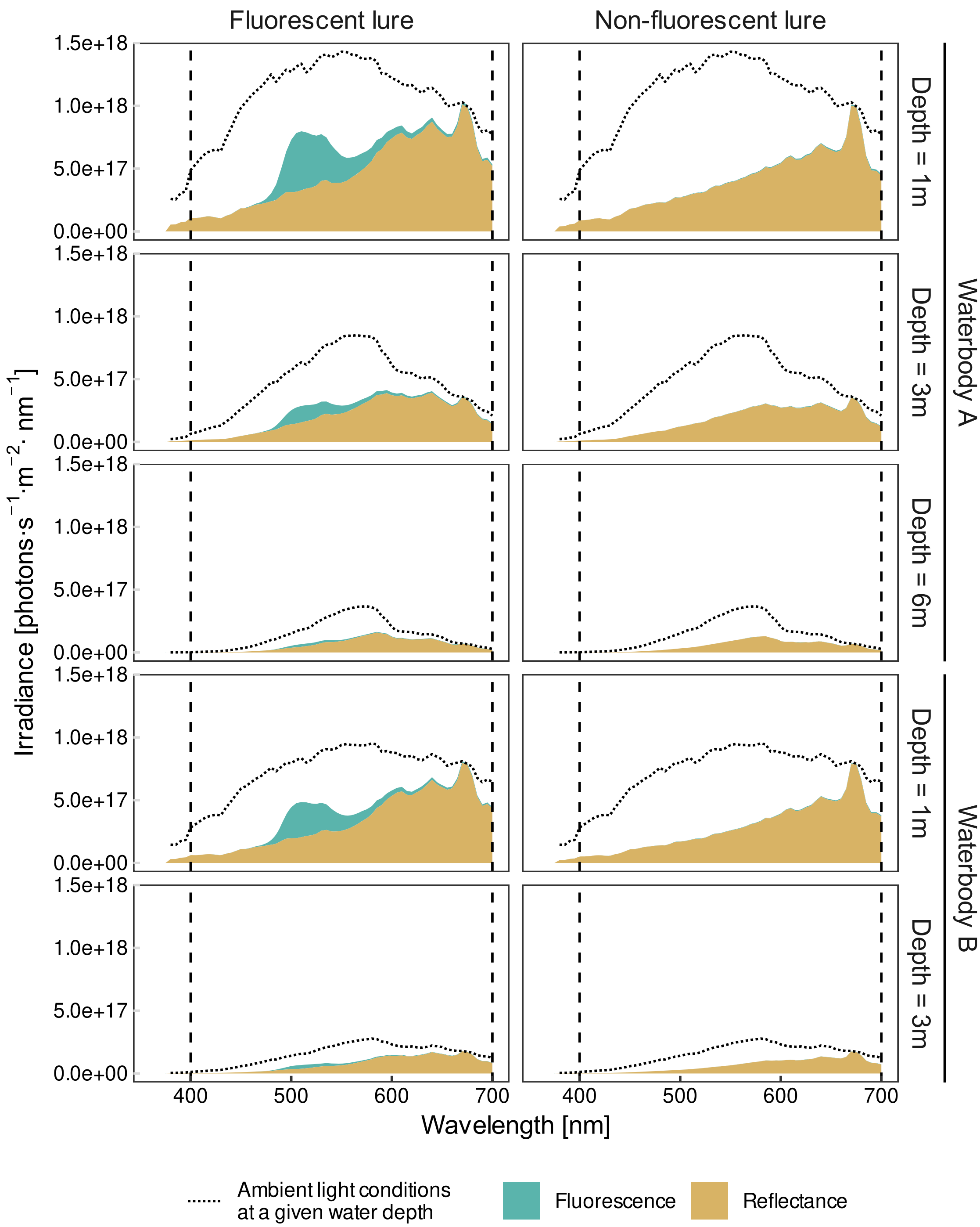
We found that the sixteen fluorescent lures examined under controlled laboratory settings were primarily excited by

Fig. 3. Excitation wavelength and corresponding emission wavelength of the 16 fluorescent lures at their maximum light emission. Marginal plots show spectral profiles for excitation (top) and emission (right) for each lure that intersect peak light emission (indicated by the points) and corresponding boxplots (median, box: 25 and 75 percentiles, whiskers: 10 and 90 percentiles). The points resembling the individual lures are colored for their emission wavelength according to how the average human eye would perceive it (Stockman and Sharpe 1999). The fluorescent lure (Easy Shiner, color: Motoroil) used in the angling trials is indicated by the diamond marker. Diagonal solid line indicates the 1:1 line; dotted vertical line indicates boundary of the ultra-violet range at an excitation wavelength of 400 nm.



blue light rather than UV radiation. Only two of the studied fluorescent lures were majorly excited by wavelengths within or close to the UV spectral range (≤400 nm). Our laboratory test represented an arbitrary selection of different fluorescent lures types and brands anglers typically encounter in German angling stores, including soft plastic baits as well as metal, plastic, and wooden hard baits from popular manufacturers, and therefore did not cover a systematic analysis of the full range of lure types or manufacturers, especially in international markets. While our results are specific to the tested lures, they indicate that a common labeling of fluorescent lures as "UV lures" by the angling industry and anglers (OTW Staff 2013; Beyer 2018; Norff 2020) can be misleading and may create misunderstandings about a lure's conspicuousness. Some anglers appear to attribute the high conspicuousness of fluorescent lures to an optical illusion caused by UV excitation (OTW Staff 2013; Norff 2020), which our results suggest is unlikely at least for the lures tested. Fluorophores that emit a wavelength range around the optimum human spectral sensitivity, can also get excited with a wavelength that is close to the limit of the human spectral sensitivity or beyond it, especially from the UV wave spectrum. This creates a false "glow" effect of a "UV lure" when excited by UV radiation for the human observer. Some anglers assume that this glow effect increases the conspicuousness of fluorescent lures for the fish under water (OTW Staff 2013; Beyer 2018; Norff 2020). Yet, a natural environment during daylight is always illuminated by a broad wavelength range (Cronin et al. 2014), which may (in clear water) or may not (in turbid water or water with high particle loads) include UV radiation. The conditions for an optical illusion with a highly concentrated excitation wavelength thus rarely occur in nature. Ad-

Fig. 4. Ambient light conditions and corresponding reflectance and fluorescence emission of the fluorescent (left) and the nonfluorescent "Easy Shiner" lure (right) used in the angling trials. Relative contribution of reflectance and fluorescence to the total spectral emission under ambient spectral photon irradiance are plotted across water depths.



ditionally, different species have different spectral sensitivities (Cronin et al. 2014; Jokela-Määttä et al. 2019). Therefore, whether fishes can see the emitting light spectrum of a "UV lure" depends on the species and the very peculiar properties of a given waterbody and of the lure. We have seen the tested "UV lures" available on the angling market show drastically different maximal emitting wavelengths and that many of them also show fluorescence when excited by wavelengths that are visible to the human eye. In other words, it is possible that a catch enhancing effect of a so-called "UV lure" is caused by fluorescence not to excitation by UV radiation, but to excitation by longer wavelengths. Clearly, very specific properties of the ecosystem and daylight will interact to affect which spectral environment occurs in water depths where a lure is presented to the fish, resulting in even higher complexity of interactions with the specific material of which a lure is com-

Table 1. Results of generalized linear mixed models for perch catch per unit effort and size of caught perch.

Model	Perch CPUE		Perch size	
Response variable; model family	Ind. perch/30 min; Poisson (log-link)		Perch body length (mm); Gamma (log-link)	
Fixed effects	Effect size (CI)	p	Effect size (CI)	*p*
Intercept	**− 1.39 (−2.47 to −0.54)**	**0.003**	**5.19 (4.96 to 5.39)**	**<0.001**
Lure type (Fluo)	− 0.51 (−1.23 to 0.21)	0.086	0.12 (−0.03 to 0.27)	0.147
Daytime (Midday)	− 0.01 (−0.62 to 0.65)	0.978	0.06 (−0.07 to 0.20)	0.372
Daytime (Evening)	0.20 (−0.31 to 0.78)	0.366	0.00 (−0.11 to 0.12)	0.951
Illuminance	**0.01 (0.00 to 0.02)**	**0.028**	− 0.00 (−0.00 to 0.00)	0.355
Cloud cover	**0.01 (0.00 to 0.01)**	**0.017**	0.00 (−0.00 to 0.00)	0.953
Angling depth	**− 0.31 (−0.65 to −0.02)**	**0.044**	**0.07 (0.02 to 0.12)**	**0.006**
Lure size (large)	**− 0.50 (−0.96 to −0.07)**	**0.027**	0.07 (−0.06 to 0.18)	0.316
Lure position (Bottom)	**0.33 (0.10 to 0.57)**	**0.003**	0.02 (−0.04 to 0.08)	0.507
Lure type (Fluo) × daytime (midday)	0.56 (−0.33 to 1.48)	0.178	− 0.13 (−0.34 to 0.06)	0.231
Lure type (Fluo) × daytime (Evening)	0.17 (−0.58 to 0.99)	0.615	− 0.05 (−0.23 to 0.12)	0.578
Lure type (Fluo) × illuminance	− 0.01 (−0.02 to 0.00)	0.089	0.00 (−0.00 to 0.00)	0.421
Lure type (Fluo) × cloud cover	− 0.00 (−0.01 to 0.01)	0.377	0.00 (−0.00 to 0.00)	0.539
Lure type (Fluo) × water depth	0.13 (−0.28 to 0.53)	0.472	0.04 (−0.03 to 0.10)	0.277
Random effects				
σ^2 waterbody	0.136		0.002	
σ^2 angler	0.047		0.012	
σ^2 month	0.43		0.018	
n waterbody	3		3	
n angler	7		7	
n month	5		5	
n observations	986		323	

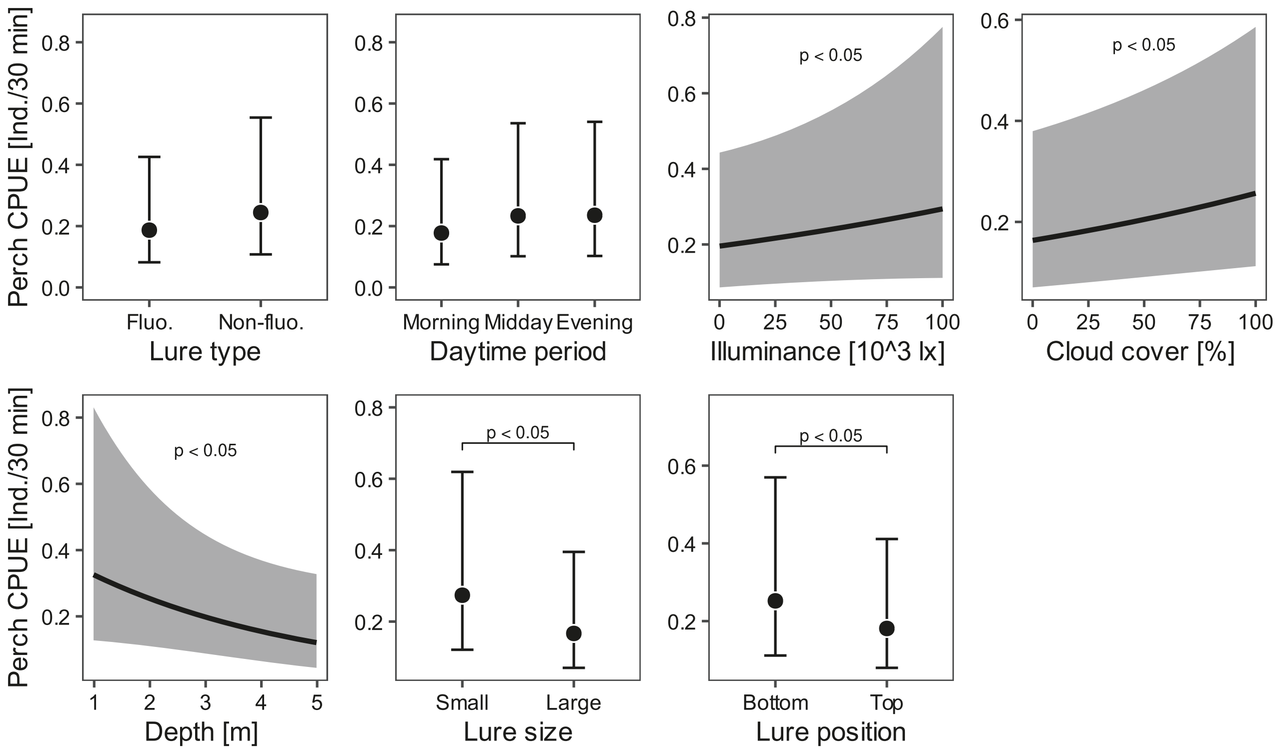
Note: Effect size estimates are provided with corresponding bootstrapped 95% confidence intervals (CI) in parenthesis. Significant effects ($p < 0.05$) are indicated in bold. CPUE, catch per unit effort.

posed. This complexity precludes generalized conclusions as to how the average fluorescent lure will appear and be perceived under water.

In contrast to our primary prediction and for the specific settings of our study in terms of experimental lure and photophysical properties of the study systems (e.g., excitation wavelengths that got strongly attenuated with depths in the studied meso- to eutrophic waters), using the fluorescent soft plastic lure (of the brand KEITECH®) did not increase catch rates compared to the nonfluorescent lure nor did lure type affect the size of caught perch. These findings align with earlier research conducted on largemouth bass (*Micropterus salmoides*) (Wilde et al. 2003; Moraga et al. 2015), spotted mackerel (*Pneumatophorus tapeinocephalus*) (Hsieh et al. 2001), and multiple fish species (predominately Auxis spp.) in the Bongao waters in the Philippines (Ajik et al. 2023) that also found no clear evidence of lure color influencing catch rates of targeted species. However, studies on rainbow trout (*Oncorhynchus mykiss*) (Ateşşahin and Cİlbiz 2019) and walleye (*Sander vitreus*) (Nieman et al. 2020) revealed that lure color can influence catch rates in these species. Conclusively, our and previous studies suggest that color effects might depend on the target species, ambient environmental conditions, the specific lures used and most likely a complex interaction of all three factors.

We note that, unlike previous research, our study did not measure the catch-enhancing effects of color acquired by reflection. Thus, our study did not address whether reflection-generated hues affect perch vulnerability to angling. Instead, we focused on lures with similar reflective spectra but differing fluorescence abilities. Our radiometric analyses revealed that under the average light environment to be expected in the study waterbodies, it is very likely that the experimental fluorescent lure achieved somewhat greater conspicuousness (with an additional emission in the green spectrum) than the nonfluorescent lure in depths to maximally 3 m. For an organism that can distinguish the fluorescence emission from the reflection, the fluorescence signal should outweigh the small differences of the two reflection spectra. Yet, even if this was the case, either the effect was not strong enough or it was, on average, irrelevant for perch angling. If at all, the effect was even slightly negative. It is of course possible that other lure types with different reflective properties would result in different outcomes in perch angling. And it is equally

Fig. 5. Main effects of lure type and environmental characteristics on perch catch per unit effort (CPUE) (Ind./30 min angling trial). Effects refer to model-estimated marginal means and their corresponding 95% confidence intervals/bands. Displayed results for a given effect are averaged over the levels of the other effects. Details on model coefficients are provided in Table 1. Interaction effects with lure type are displayed in Fig. S3.



possible that our study design, which was tailored to detect average catch rates effects over the day, precluded identifying effects of fluorescence on catch outcomes emerging at higher temporal resolutions during the day and under particular light conditions.

Our study did not detect an effect of fluorescent lures on perch vulnerability to hooks or the size of caught perch angling under the conditions tested in shallow, meso- to eutrophic freshwater systems. While this does not rule out possible effects in other contexts with different fluorescent lures, other water bodies or involved anglers, it provides a first experimental test of the widely held and often generally stated assumption that fluorescent lures increase catch rates or size. Moreover, we did not detect significant effects of the tested lure's fluorescence properties on hooking depth (Table S6.1), suggesting that, under the conditions tested, fluorescent lures are unlikely to cause additional adverse effects on fish compared to nonfluorescent lures, e.g., during catch-and-release. Catch rates being unaffected by fluorescence in our study contradicts earlier research on natural predator–prey systems, which found that fluorescent prey (however without accounting for reflectance effects) was favored by species such as largemouth bass (Hill et al. 2011). Since the tentacle tips of a predatory hydromedusa attracted more fish (juvenile rockfishes in the genus *Sebastes*) in the presence of excitation wavelengths compared to their absence (Haddock and Dunn 2015), it is possible that the fluorescence-emitted wavelength of the lure used in this experiment was too rapidly absorbed or did not alter the contrast among the lure and the background before reaching the perch eye.

Contrary to some anglers' assumptions (OTW Staff 2013; Beyer 2018; Norff 2020) and in contrast to our predictions, none of the environmental variables interactively influenced the catch outcome of the studied fluorescent vs. nonfluorescent lure. Catch rates of both lure types were affected similarly by illuminance, cloud cover, daytime, and water depth. For example, our results showed that catch rates for both tested lures similarly decreased with increasing water depth under the conditions studied, contradicting anglers' assumptions that fluorescent lures would generally improve catch rates at greater depths (OTW Staff 2013; Beyer 2018; Norff 2020). While catch rates decreased with water depths, the size of captured perch was larger at deeper depths, irrespective of the used lure type. In perch, especially the smaller size classes are associated with shallow littoral habitats where they are generally more abundant due to improved food availability and reduced predation risk (Lewin et al. 2004; Hölker et al. 2007; Maday et al. 2023), which likely explains the observed water depth related effects on catchability.

We found that the perch catch rate was affected by some environmental variables, irrespective of the studied lure type. Illuminance had a positive effect on catch rate of perch, supporting previous notions of the light environment being

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highly important for the vulnerability of fishes to be caught by anglers (Kuparinen et al. 2010; Stevenson and Millar 2013; Cooke et al. 2017; Lennox et al. 2017). European perch are visual predators that decrease food uptake and become largely inactive at dark (Schleuter and Eckmann 2006; Nakayama et al. 2018), which is also reflected in our findings of lower illuminance being associated with lower catch rates. Our findings indicated that cloud cover positively influenced perch catch rates suggesting an independent cloudiness effect dissociated from the illuminance, which might be related to the directionality of light. Previous research showed mixed effects of cloud cover on fish behavior: Atlantic salmon (*Salmo salar*) foraging decreased under cloud cover (Girard et al. 2003) while northern pike (*Esox lucius*) were observed to forage more actively on cloudy days (Casselman 1978) and generally under twilight (Kuparinen et al. 2010). In addition to reducing total irradiance, clouds also alter the downwelling light spectrum by scattering shorter wavelengths (blue-violet), increasing their relative contribution, while absorbing longer wavelengths (red) (Bartlett et al. 1998). Moreover, the sky is less blue with cloud cover and thus cloud cover might, depending on the viewing direction, affect the contrast of the lure. However, it remains unclear whether the differing cloud cover effects are attributed to spectral properties, species-specific differences or other factors. We assume that interactions of light and cloud cover lead to micro-level variation in the contrast between the lure/prey and the background, affecting the perch (and other predators) to either attack or not (Jönsson et al. 2011; Khan et al. 2023), but higher resolution studies under changing light and cloudiness conditions within the day are needed to quantify this assumption, which was beyond our study.

In our experiment, the smaller lure size had a higher catch rate compared to the larger lure. Due to gape size limitations the lure size generally affects the length of the fish caught (Wilde et al. 2003; Arlinghaus et al. 2008; Lennox et al. 2017). However, our findings did not indicate such lure size dependent effects on size of perch caught, which might be caused by the rather narrow overall size range (50% of all fish within 13–22 cm) and the comparable small differences in lure size (5.4 cm vs. 7.2 cm). Instead, we interpret the catch-rate-enhancing effect of the smaller lure as being due to its size, which perch may perceive as easier to ingest, or which may increase the probability of successful hooking after a bite. Our finding of increased CPUE when using smaller lures aligns with a previous study on different salmonids (Orsi 1987) but is in contrast to a study on larger size classes of largemouth bass, which did not find a lure size–CPUE relationship in bass larger than 305 mm (Wilde et al. 2003). We assume using a sufficiently small lure enables anglers to catch more fish from the population because it does not create gape limitations—a crucial size-dependent factor for perch (Byström et al. 2012)—while still allowing larger fish to attack the lure. Such patterns might explain our inability to find an effect of lure size on the length of the caught perch. Moreover, size structures of fish populations are often skewed towards smaller individuals, also in European perch (Claridge et al. 1986; Magnhagen 2006). Therefore, fishing even larger lures than the one we used should decrease catch rates, as they exclude the more abundant size classes, resulting in a lower encounter rate with fish capable of swallowing the lure (Lennox et al. 2017).

Many European freshwater ecosystems are eutrophic (European Commission 2021), which makes our findings obtained from shallow, meso- to eutrophic systems geographically widely relevant. However, our findings might not necessarily be applicable to other fluorescent lures and other waterbody and environmental conditions especially deeper oligotrophic lake ecosystems. The 16 fluorescent lures analyzed showed a broad excitation wavelength range, with most being primarily excited by blue light, and many also by green light. This enhances their potential to fluoresce in ecosystems, where green light has potentially high transmission (see Box 1; Dodds and Whiles 2019). As algae communities often absorb red light (Dodds and Whiles 2019), fluorophores that are excited by green light and emit red light could be particularly conspicuous under conditions where red light is scarce. In oligotrophic systems, however, blue light has higher transmission (Dodds and Whiles 2019), enabling all lures analyzed in our study to potentially fluoresce even in deeper waters. The actual fluorescent properties in a given lake will also strongly depend on water depth and daytime, through affecting the downwelling of light. Our study systems were overwhelmingly shallow below 6 m water depth, so that very little can be inferred from our study for oligotrophic, deep lakes or marine ecosystems.

In summary, the ability of the tested angling lure to fluoresce did not increase the catch rate nor the size of caught perch compared to a nonfluorescent lure under various ambient conditions of daytime, illuminance, cloud cover, and water depth in shallow meso- to eutrophic systems. Yet, this study also shows that fluorescent lures sold to anglers have the possibility to be conspicuous in waterbodies that allow excitation wavelengths to penetrate deep enough to excite fluorophores. The actual conspicuousness of fluorescent lures will depend on the characteristics of the fluorophore in combination with environmental water conditions. In the study presented and under the conditions we studied, the tested fluorescent lure was not superior in terms of angling catch rates compared to the nonfluorescing one. Clearly, the scope and generality of our finding, that fluorescent lures have no impact on catch success in perch, are limited, as we did not replicate the test of fluorescent effects across multiple lures, brands, and water body types. Future studies are recommended to examine other fluorescent lures in a wider range of waterbodies.

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The data and analysis scripts underlying this study are available via Figshare at https://doi.org/10.6084/m9.figshare.28310012. Datasets on spectral irradiance were derived from https://doi.org/10.5442/ND000010.

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The authors declare there are no competing interests.

Supplementary material

Supplementary data are available with the article at https://doi.org/10.1139/cjfas-2025-0084.

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