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Environmental Pollution by Lost Fishing Tackle: A Systematic Assessment in Lake Eixendorf

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Abstract: Environmental pollution by lost fishing tackle is hardly considered in freshwater management. We collected and classified lost angling tackle during the dewatering of Lake Eixendorf, Germany. Based on the results, 1 item per 100 m^2 lake area was found, resulting in 5442 items, with an overall weight of more than 65 kg. This included more than 5 km of braided and monofilament fishing lines of various diameters. Lures used for active fishing methods such as stickbaits (shads and twister), metal spoons, spinners, and hard plastic baits had the greatest weight contribution (53.4%). Tackle lost from passive fishing methods (45.1%) mostly comprised groundbaiting feeder baskets and classical lead sinkers. Concerning the chemical composition, most lost items contained a composite mix of different materials. Lead was most abundant (45 kg), followed by plastics (13 kg) and steel (6 kg). Other materials such as copper, aluminum, brass (altogether 376 g), and chemicals from glow sticks (25 g) were less frequently found. Environmental pollution by lost fishing tackle deserves attention and, due to its potential environmental consequences, needs to be integrated into the pollution management of aquatic ecosystems, e.g., by identifying the most problematic items and by regulating the production and use of gear containing hazardous substances.

Keywords: recreational angling; sport fishing; lead contamination; plastic pollution; freshwater; plasticizers; microplastics

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1. Introduction

Pollution is considered one of the six most important threats to freshwater biodiversity [1,2]. Freshwater pollution occurs on different scales over various pathways, comprising point sources such as industrial or urban sewage as well as diffuse inputs from agricultural land use [3,4]. Especially in intensively used aquatic ecosystems, the sources of environmental pollution are often associated with human uses and activities [5]. Besides the well-known point and diffuse sources of pollution, there are other less obvious sources of environmental pollution associated with recreational activities such as the input of sunscreen or insect repellents by swimmers [6,7]. Another important recreational activity is angling, with well-described impacts on fish populations [8], the management of aquatic systems [9], invasive species introduction [10], as well as economic aspects [11]. Whilst these effects of angling are well-documented, other potential impacts of angling related to environmental pollution are less clear. During prime season, lakes and rivers can get crowded by anglers, potentially resulting in trampling and damage to shorelines as well as littering [12–14]. Another less obvious impact relates to fishing tackle, e.g., when hooks get snagged on the bottom. In commercial fisheries of marine systems, lost fishing gear, especially ghost nets (abandoned, accidentally lost, or deliberately discarded gill nets), are recognized as an increasing problem with harmful effects on marine fauna [15]. Depending on the mesh size, this can be a major threat for turtles, in particular, resulting in catch rates of up to four turtles per 100 m of net length for fine-mesh gill nets [16]. In addition to these direct effects, the weathering of ghost nets that often consist of polypropylene lines can be a source of marine microplastics [17]. However, largely unseen is the garbage left behind by anglers in aquatic ecosystems attributed to the loss of tackle by fishermen that is often unavoidable in sport fishing.

In this study, we used a frequent dewatering event of Lake Eixendorf in Germany to collect and classify all the parts and types of lost angling tackle found in the dewatered area of the lake. The main objectives of this study were to (i) qualitatively characterize the types of lost fishing gear, and (ii) semi-quantitatively determine the relative abundance of the different types of lost tackle in order to determine the main problems concerning the potential environmental effects of lost angling gear in a typical central European reservoir fishery.

2. Materials and Methods

2.1. Site Description

The collection of angling trash was carried out during regular dewatering for maintenance reasons in Lake Eixendorf. Lake Eixendorf is an artificial reservoir impounding the River Schwarzach nearby the city of Rötz, Bavaria, Germany (49.3394 N, 12.4794 E, Figure 1) since 1975. The lake surface area at the mean water level is 100 ha, and the maximum surface area at full load is 185 ha. At the mean water level, the lake is 6.5 km long, 75 m wide at its widest section, and 13 m deep. At this stage, it stores 150,000 m^3 of water and has a maximum storage capacity in case of floods of 19,300,000 m^3. The water authorities maintain the reservoir on a regular basis, and the last dewatering took place in the year 2016. Five years later, in 2021, the water level had to be lowered again, providing the opportunity to collect and classify the angling-associated trash collected from the lake bottom after a defined five-year period. The dewatered area can differ in magnitude due to the respective purpose and can range from complete dewatering (https://www.wwa-wen.bayern.de/fluesse_seen/gewaesserportraits/eixendorf/, last accessed on 29 July 2022) to only lowering the water 6.25 m below the mean water level as practiced in 2021. Between 2016 and 2021, the water level remained almost constant, with only marginal operational water level fluctuations during that period. The fish community in the reservoir comprises a large proportion of prominent sportfish such as European catfish, northern pike, pike-perch, asp, common carp, common bream, and European perch [18]. Recreational fishing in the lake is managed by the local angling club, the Fischereiverein Neunburg e.V., which has around 500 members. The club also sells fishing permits and is responsible for fishery management including stocking (https://www.fischereiverein-neunburg.de/gewaesser/eixendorfer-stausee, last accessed on 29 July 2022).

2.2. Collection and Treatment of Items

The entire lake bottom surface area of 541,000 m^2 (Figure 1) that dried up during the dewatering in 2021 was screened for sport fishing garbage such as fishing lines, artificial baits, sinkers, floats, hooks, and other items associated with angling activities. The collected items were found attached to roots and stones, or they were simply stuck in the mud. The cleaning survey was carried out between 9:00 a.m. and 6:00 p.m. on a daily basis with 18 people (mean = 7 people per day) over 27 working days between 13 September 2021 and 19 October 2021. All items were pre-sorted, subdivided into non-angling or angling trash, and collected in large plastic bins. Angling trash was transported to the lab, where it was rinsed with tap water before further classification. Every single item was individually classified, measured, weighed, and assigned to a specific tackle category (Table 1 and Figure 2).

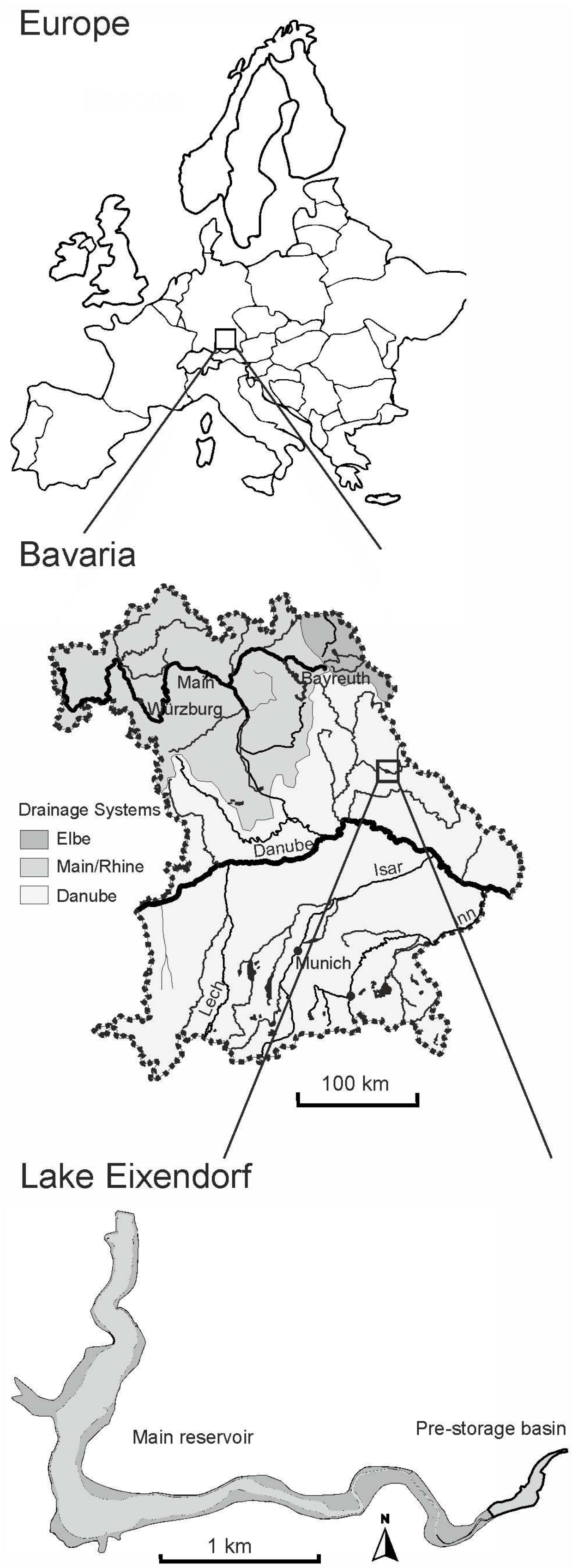

Figure 1. Map of the study area within Europe, Bavaria, and Lake Eixendorf. Dark grey area in the lower part (Lake Eixendorf) indicates the accessible and sampled area during the dewatering.

Table 1. Classification of lost fishing tackle found in Lake Eixendorf attributed to active and passive fishing methods or not being attributed (N.A.). Items are displayed in Figure 2. Overall = weight (g) of items (n) for the respective item class, condition of items is attributed to N = new, G = good, M = medium, P = poor, or R = rotten.

		Overall		**N**		**G**		**M**		**P**		**R**	
		(g)	**n**	**(g)**	**n**	**(g)**	**n**	**(g)**	**n**	**(g)**	**n**	**(g)**	**n**
Active	Shads and twister	26,868	1690	835	58	4695	278	5548	315	11,204	668	4621	371
	Jigheads	2820	247	105	11	484	42	617	52	1170	106	444	36
	Spoons	2679	116	142	7	474	24	681	27	1072	47	311	12
	Spinner	1059	85	194	12	157	10	204	13	501	48	4	2
	Lures and jerkbait	681	30	85	2	158	7	158	7	273	13	6	1
	Trolling devices	551	40	53	3	208	15	170	14	107	7	12	1
	Flies	126	13	0	0	2	1	0	0	79	9	45	3
Passive	Feeder baskets	15,717	435	1196	29	4234	92	4210	102	3912	101	2763	111
	Sinkers	12,109	413	659	45	5219	148	2327	69	3728	147	176	3
	Boilie bombs	296	6	0	0	129	2	163	3	5	1	0	0
	Antitangle boom	287	213	0	0	99	73	47	31	125	89	13	17
	Floats	226	26	47	1	67	8	1	1	93	10	18	6
	Hooks	175	344	18	35	32	63	47	92	43	85	35	69
N.A.	Cast connectors	481	163	28	94	70	238	202	684	134	453	47	159
	Not classified	475	158	147	1	115	6	78	123	111	13	23	15

Figure 2. Diversity of angling gear collected in Lake Eixendorf. A = soft bait, twister, and shads with twister tail; B = soft bait, shads with and without jighead; C = metal spoons; D = spinner and spinner bait; E = hard plastic lures; F = lost jigheads; G = feeder baskets; stand-up sinkers; H = lead sinkers; J = underwater floats; K = floats; L = rod holders and broken fishing rods; N = braided fishing line; M = steel leader; O = monofilament fishing line.

Due to the different stages of the degradation of the found items (Figure 3), each of them was assigned to one of five groups representing distinct stages of degradation: new (N) = new items with almost no signs of usage; good (G) = items showing little signs of usage, but still fully functional; medium (M) = items comprising clear signs of usage or degradation, with their function being partly restricted; poor (P) = items showing strong signs of degradation, with no function remaining; rotten (R) = items being almost completely degraded. Since many items were made of composite materials comprising a combination of several pieces of different materials, e.g., soft baits such as shads that consist of a lead head, a steel hook, and a plastic body (Figure 4), they were disassembled into their individual parts (materials), and these were weighed (to the nearest 0.1 g) and measured (to the nearest mm) (Table 2). To determine the overall length of the collected fishing line, a representative subset of the line pieces of monofilament line, braided line, and steel leader material of different diameters were individually measured and weighted. Then, for each of the three line types, the overall length was individually calculated (Table 3). It has to be noted that the dried-up banks were very muddy, which potentially led to some items not being found during the survey, resulting in an underestimation of angling trash. This particularly holds true for small and heavy items that were potentially stuck deep in the mud.

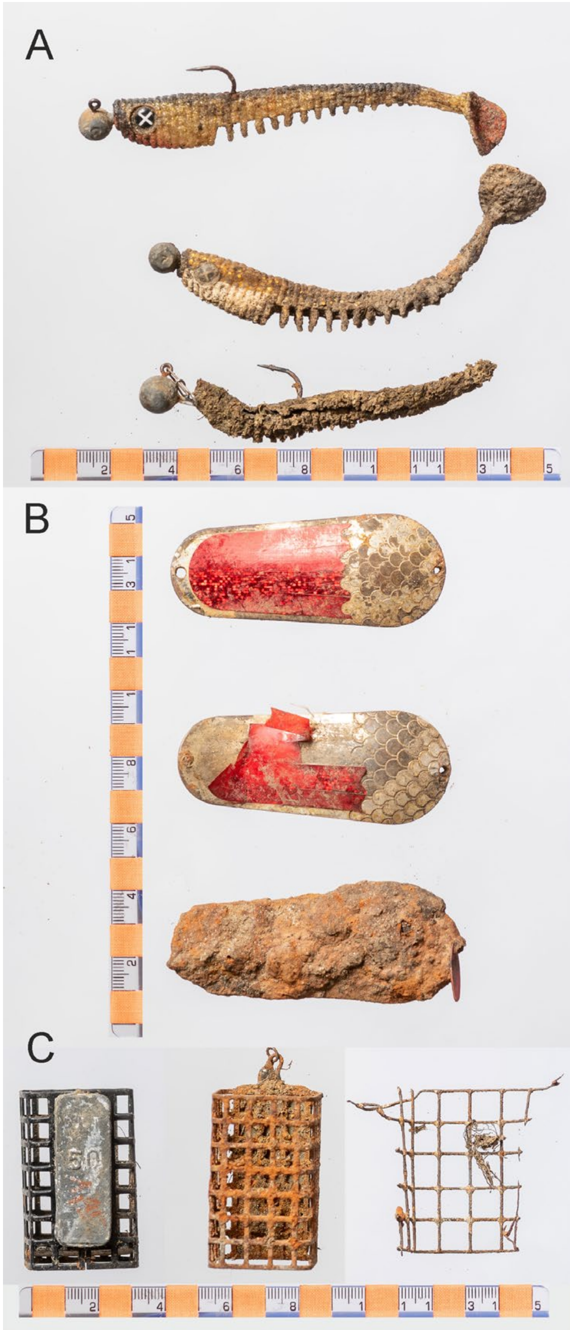

Figure 3. Different stages of degradation of (**A**) soft bait and (**B**) hard bait as well as (**C**) feeder baskets found in Lake Eixendorf.

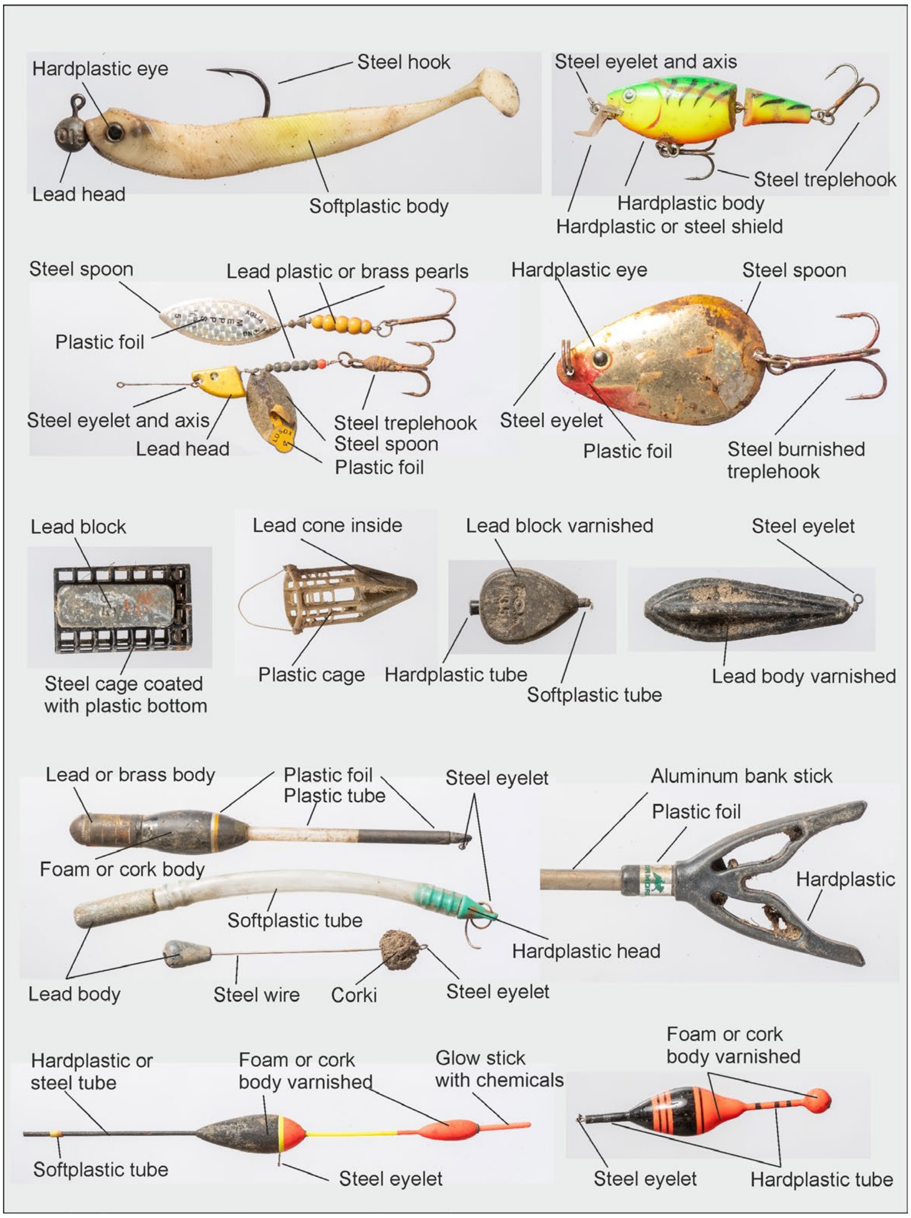

Figure 4. Examples of collected angling items in Lake Eixendorf that represent compound materials. Note that steel materials can also contain nickel or zinc and that all plastic items were solely classified as soft plastic or hard plastic. We are aware that these materials can widely differ in their chemical composition.

2.3. Data Analysis

For comparisons of the individual weight measurements of the found angling items, each dataset was tested for normal distribution (Shapiro–Wilk test) and homoscedasticity (Levene's test). Since the data did not fulfill the criteria for parametric testing, the nonparametric Kruskal–Wallis test was applied to test if the median values significantly differ between groups or between the respective condition classifications inside groups. To determine the maximum potential environmental impact of some materials such as lead potentially entering the aqueous phase, the total weight of the lead found during the survey was divided by the water volume of Lake Eixendorf at a normal water level (150,000 m^3). Concerning plasticizers (originating from stickbaits such as shads and twisters), a subset of the exact same makes and models of new and rotten shads and twisters were individually weighted, and the difference in weight between the two condition classes "new" and "rotten" was determined. Since it turned out that these items can lose more than 75%

of their weight during degradation, 75% of the total weight of stickbaits was divided by the water volume in Lake Eixendorf at the normal water level for a rough estimate of the contamination potential.

Table 2. Identified components of lost fishing tackle found in Lake Eixendorf. Note that some of the materials, e.g., "steel", can consist of several components including zinc or nickel. The same holds true for fishing lines that can consist of either polyamide, polyethylene, or other polymers. Mean = mean weight per item, min = minimum weight per item, max = maximum weight per item, n = number of items containing the substance.

		Weight (g)			
	n	**Overall**	**Mean/Item**	**Min**	**Max**
Steel	4567	6387	1.4	0.1	55.6
Lead	2409	44,998	18.7	0.2	183.6
Soft plastic	1879	11,368	6.1	0.1	70.0
Hard plastic	1085	1642	1.5	0.1	65.9
Copper	13	47	3.6	0.2	10.4
Balsawood	12	26	2.1	0.2	4.8
Chemicals	11	25	2.2	1.0	4.2
Brass	11	22	2.0	0.2	6.6
Aluminum	8	307	38.3	4.0	140.0
Cork	7	9	1.3	1.0	3.0
Carbon fiber/Fiberglass	5	21	4.3	0.1	13.5
Stone	1	26	-	-	-

Table 3. Length and weight of the collected fishing line and steel leaders. Note that fishing lines can consist of either polyamide, polyethylene, or other polymers. Steel leader material can be manufactured with different tempering and can contain components such as zinc and nickel, and it can be coated with plastics. Diameter gives the minimum and maximum measured diameter of the line or steel leaders found.

	Length (m)	**Weight (g)**	**Diameter (mm)**
Monofilament line	3138	104	0.10–1.00
Braided line	1724	336	0.08–1.20
Steel leader	334	309	0.08–0.50

3. Results

Overall, 5442 items, i.e., 1 item per 100 m^2, of lost fishing tackle with an overall weight of 65.15 kg (Table 1), comprising 3138 m (0.10–1.00 mm diameter) monofilament line, 1724 m (0.08–1.20 mm diameter) braided line, and 334 m (0.08–0.50 mm diameter) steel leader material (Table 3), were collected during the cleaning of the area of Lake Eixendorf that had dried.

The largest weight proportion (53.4%) of lost tackle could be attributed to active fishing methods using artificial baits such as soft plastic stickbaits (shads and twisters), metal spoons and spinners, or hard plastic lures. The material related to passive fishing methods such as groundbaiting using feeder baskets and classical lead sinkers of various shapes contributed 45.1% of the collected angling-associated trash. A small percentage (1.5%) could not be clearly attributed to active or passive fishing methods (Table 1). The most items found were stickbaits (soft plastic) such as shads and twisters (1690 items) with a mean size of 8.8 cm (min = 0.5 cm, max = 20.5 cm) and mean weight of 15.9 g (min = 0.1 g, max = 101.2 g). Since the body of these items is usually attached to a jighead, these items contain both a soft plastic body (mean weight = 6.6 g, min = 0.1 g, max = 70.0 g) as well as a hook embedded into a lead head (mean weight = 11.1 g, min = 0.8 g, max = 82.0 g). Besides the high number of cast connectors (1628 items), which consisted mainly of steel and had a relatively small weight proportion (481 g) compared with the other found items, feeder baskets and sinkers could be found in high numbers (altogether 848 items, Table 1). The feeder baskets were made in principle out of a steel case to keep the decoy feed, an attached lead block (mean weight = 32.4 g, min = 0.2 g, max = 136.0 g), and a steel connector to the fishing rig (Figures 2–4). The sinkers consisted of a lead body (mean weight = 29.4 g, min = 0.5 g, max = 183.6 g) and a steel connector. Besides stickbaits (lead content 18.6 kg), these two item classes (feeder baskets (14.0 kg) and sinkers (11.9 kg)) contributed the most to the overall weight proportion of the lead (45.0 kg) found during the survey. The second most found material was soft plastic (11.4 kg), followed by steel (6.4 kg), and hard plastic (1.6 kg). Other materials such as copper, aluminum, and brass (altogether 375.8 g) or chemicals of glow sticks (24.6 g) were present in lower numbers and weight contributions (Table 2). Assuming simplified steady-state conditions with no water exchange as well as that potentially all the lead would go into solution, the potential lead content at the mean water level of Lake Eixendorf could reach concentrations of up to 300 mg m^{-3}. Under the same scenario, plasticizers originating from the soft plastic of stickbaits could reach concentrations up to 60 mg m^{-3}.

Concerning the degradation of the items that were classified into the five classes, the greatest proportion of the collected items was in poor (33.0%) or medium (28.2%) condition, fewer were in good (18.5%) or new (5.5%) condition, and 14.8% of the items were strongly degraded and classified as rotten. Stickbaits (shads and twisters) were mostly found in poor or rotten conditions (59.5%). Overall, rotten shads and twisters lost 13.2% of their mean weight (Figure 5) compared with new ones. Comparing only the new and rotten soft baits of the same type and length, stickbaits lost even a higher percentage of their weight (75%) due to degradation (Figure 6). Rotten feeder baskets lost 39.6% mean percentage of weight compared with the new items of this tackle class.

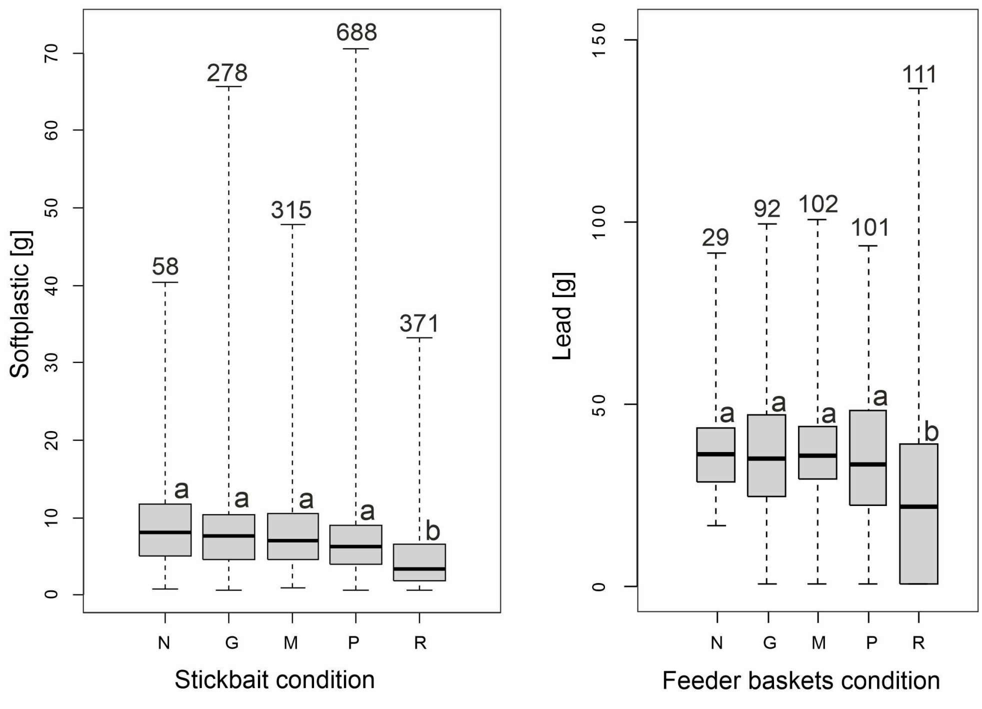

Figure 5. Box–whisker plot (25% quantile, median. 75% quantile, whisker: minimum and maximum values) of the weight proportion of soft plastic (g) in stickbaits and lead (g) in feeder baskets attributed to five different conditions. N = new, G = good condition, M = medium condition, P = poor condition, and R = largely rotten item. Letters above the median indicate significant differences between items. Numbers above the whisker indicate the number of items in the respective group.

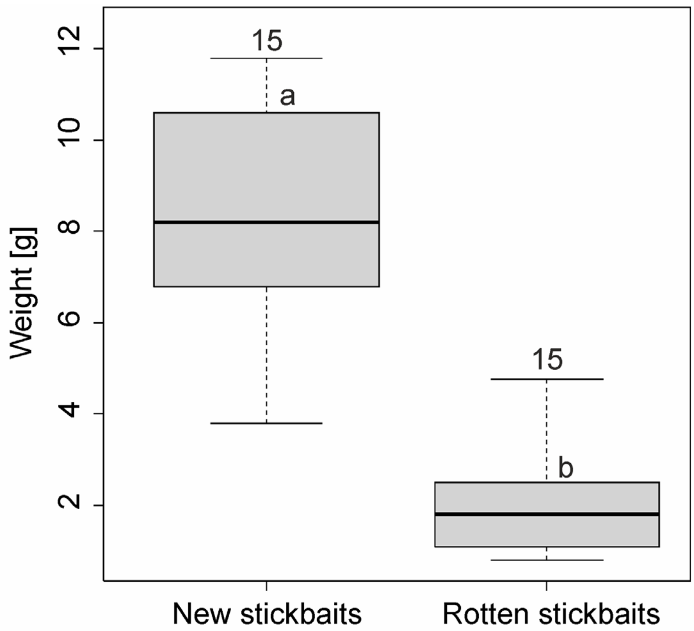

Figure 6. Box–whisker plot (25% quantile, median. 75% quantile, whisker: minimum and maximum values) of the weight proportion of a subset of the exact same makes and models of new and rotten shads and twisters. Note that only the soft plastic body of the items without lead head and hook were considered for this analysis. Letters above the median indicate significant differences between items. Numbers above the whisker indicate the number of items in the respective group.

4. Discussion

The intention of this study was to provide novel insights into the quality and magnitude of environmental pollution by spent angling tackle in a typical Bavarian lake. We are aware that the amount of angling trash and the different types of items can largely vary between different aquatic habitats, depending on factors such as angling intensity, habitat structure, the target species of angling as well as the applied active or passive angling methods. Since no cleaning survey will be able to discover all lost fishing tackle, particularly if the items are small, heavy, and potentially stuck unseen deep in the mud, the data provided in this study can be considered the data of a rather conservative approach that potentially underestimates the real extent of pollution. Other angling-associated inputs such as the nutrients introduced by groundbaiting and feeding were not assessed in this study. Nevertheless, these also have the potential to result in environmental effects [19], particularly in oligotrophic ecosystems such as alpine lakes or in eutrophic lakes that suffer from hypolimnetic oxygen deficits during summer stagnation.

In Lake Eixendorf, an unexpectedly large variety of different items could be found, and the density of these pollutants, with one item per 100 m^2 lake bottom, was surprisingly high. Depending on the type of lost equipment, different potential environmental impacts and effects on wildlife need to be considered. Direct threats can be expected from lost fishing line that usually was found along the shoreline and attached to underwater structures. Tangled fishing lines can trap birds and mammals but also impact fish and other aquatic animals [20–22]. It is widely known that abandoned fishing nets, the so-called ghost nets, in the ocean threaten fish and other sea life, trapping fish long after they got lost [23,24]. Single hooks, artificial baits with hooks, and other sharp items detected in Lake Eixendorf could harm animals or humans if they accidentally step on them or touch them. Furthermore, artificial baits such as stickbaits or baited hooks can cause direct mortality due to structural damage such as cuts or perforations to internal organs and intestinal obstructions, and they can block the respiratory system if fish, birds, reptiles, amphibians, or mammals swallow these items (e.g., in snapping turtles, [25]). In addition, the leaching of toxic substances also needs to be considered, analogously to the leaching of such substances from shot ammunition in hunting activities at aquatic ecosystems [26,27]. The lead originating from ammunition can pose a large threat to predatory birds and other terrestrial species that may feed on shot prey but also to humans who frequently eat shot-hunted game [28–30]. It is likely that piscivorous birds feed on fish that may carry lost items such as shads and twisters that are usually attached to a hook with a lead head. Other items found in this survey also pose a most unknown risk to the aquatic environment such as copper, brass, or micro- and macroplastics that may additionally release plasticizers [31] and other toxic substances (particularly soft baits). Even steel items can have a major negative impact on the environment if the steel is quenched and tempered, containing substances such as nickel or zinc (e.g., [27,32]). These substances are very common in the sport fishing industry to improve the performance of fishing hooks, connectors, or steel leader material. Besides the threats of more or less persistent pollutants, there are potentially chronic threats resulting from plasticizers that originate from more than 13 kg of hard and soft plastic items that were clearly attributed to angling, particularly stickbaits such as shads and twisters. Besides their potential to degrade to microplastics (particles smaller than 5 mm, [31,33,34]), these items are prone to lose a large amount of plasticizer, herein more than 75% of their original weight, resulting in a solution potential of more than 60 g m^{-3} in Lake Eixendorf at the normal water level.

Different angling techniques result in different likelihoods and compositions of lost tackle. In this study, the majority of the lost tackle could be attributed to active fishing methods using artificial stickbaits that are more likely to attract piscivores, leading to a greater chance to lose fish (broken leader or line) while chasing them. This matches the expectation that active fishing methods bear a greater risk of tackle loss than passive methods. With active lure fishing, anglers use various techniques to actively search for fish, giving the bait a motion of life by casting out and reeling it in again. In structurally rich fish habitats, the chance to get snagged to an underwater structure such as stones or wood is high, particularly if the lure moves near the ground. In contrast, when applying passive methods, anglers cast out baited hooks, and it is a challenge to wait until the fish finds it. However, the bait is often presented on or shortly above the ground, and in structure-rich environments, the chances of losing tackle are also very high. In our dataset, this is reflected by the large number of feeder baskets found in Lake Eixendorf, which are exclusively used for groundbaiting and contributed to more than 30% of the found lead in this survey. Lead is a component that is intensively used in both active and passive fishing methods. Although there are some alternatives available in practice such as stone or steel sinkers or steel jigheads, these items are often more expensive than lead products [35], which could explain why they were only found in very small numbers (one stone sinker and three steel sinkers) in Lake Eixendorf.

In addition to the angling-associated pollution effects described in this study, it also needs to be mentioned that anglers are often also strongly involved in environmental protection, especially when they are part of a fishing club or organization [36]. For instance, cleaning up any kind of trash on the banks and within lakes and rivers and regular water quality monitoring are common activities in many angling clubs.

Several of the highlighted challenges arising from the results of this study, such as the high amount of lead introduced by angling, are already under discussion, and many anglers have started using lead-free alternatives (https://loon.org/loons-and-lead/non-lead-tackle-links/, last accessed on 24 August 2022). In this study, therefore, we do not intent to blame anglers for environmental pollution, particularly since they often play important roles in the surveillance of water quality, the early detection of problems, and in the sustainable management of aquatic biodiversity. Rather, we sought to draw attention to a currently hardly discussed topic in the context of fisheries and environmental pollution where improvements may be easily realized.

5. Conclusions

Despite its many positive aspects, this study shows that angling poses a large potential to pollute freshwater due to the unavoidable loss of tackle during the daily routine of sport fishing. To reduce the input of certain dangerous substances by angling, it is necessary to overthink traditional sport fishing methods, in particular related to the used materials for tackle prone to loss such as stickbaits, sinkers, and feeder baskets. In many cases, problematic materials such as lead can easily be replaced by less harmful substances for the environment such as steel. To reduce the input of plastics and plasticizers in freshwater, alternative materials should also be used for shads and twisters. Since many of the items found in this survey are compound materials with unknown components, future studies should assess their harmful potential, and an international standard should be developed for which materials can be acceptable to be used in freshwater and saltwater as well. As a precautionary measure, alternative and less harmful materials could replace the substances such as lead or plasticizers with endocrine disruptive chemicals. The market for such environmentally friendly tackle is still rather marginal, but since many anglers very much care about the environment, marketing "green tackle" may provide a competitive advantage for the industry.

Author Contributions: Individual contributions are as follows: Conceptualization, J.P. and J.G.; methodology, J.P., A.H.D. and P.H.; software, J.P.; validation, J.G.; formal analysis, J.P.; investigation, A.H.D. and P.H.; resources, J.G.; data curation, J.P.; writing—original draft preparation, J.P. and J.G.; writing—Review and Editing, A.H.D., P.H. and J.G.; visualization, J.P. and A.H.D.; supervision, J.P. and J.G.; project administration, J.P. and J.G.; funding acquisition, J.G. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data that support the findings of this study are available upon reasonable request from the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

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