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Cover Page Footnote

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Hidden Dangers to Researcher Safety While Sampling Freshwater Benthic Macroinvertebrates

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Abstract

This paper reviews hidden dangers that threaten the safety of freshwater (FW) researchers of benthic macroinvertebrates (BMIs). Six refereed journals containing 2,075 papers were reviewed for field research resulting in 505 FW BMI articles. However, danger was reported in only 18% of FW BMI papers. I discussed: 1) papers that did not warn of existing danger and consider researcher safety, 2) metric threshold values (e.g., chemical hazards), and non-metric dangers, (e.g., caves and aquatic habitats), 3), the frequency of danger occurrence, 4) baseline and extreme values. Examples of 28 danger factors that posed a threat to BMI researchers in water were compared by frequency per journal papers. FW dangers identified by metric thresholds present a safety limit not to be exceeded, whereas non-metric dangers do not have a threshold as further explained. Also, discussed was a recent thesis on civil engineering hydraulics that identified low-head dams as deceptive and an increasing source of drownings in 39 states. A safe shallow water maximum depth to wade and collect BMIs is proposed based on researcher height and gender, compared to human height means in a large database. Practical safety recommendations were presented to help protect the FW researcher avoid and survive hidden dangers.

Keywords: Researcher safety, danger factors, threshold values, accidents and drowning

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The research of freshwater (FW) benthic macroinvertebrates (BMIs) can be rewarding and or dangerous. Aquatic field work is a required part of many BMI research projects and may include a wide variety and magnitude of risks (e.g., Dewailly et al. 1986, Howarth and Stone 1990, Courtenay et al. 2012, Orr 2017). In the above papers some researchers risked death, possibly due to inexperience, unknown equipment problems, scientific goals, etc. Some extreme examples of risk include deep dives ($\geq$ 30 m) with scuba (Miyanishi et al. 2006), collecting BMIs in cave springs with high levels of toxic hydrogen sulfide (Tobler et al. 2006, 2013), accessing a deep cave with high CO_2 levels, slippery vertical surfaces, rocky substrates, groundwater fed subterranean aquifers and springs (Howarth and Stone 1990), and crossing a swift, turbulent glacial stream for sediment samples (Orr 2017). Recently, the risk of drownings has been closely associated with large dams (Tschanz 2015), and especially at low-head dams in many streams and rivers (Hotchkiss et al. 2014, Kern 2014, Tschanz 2015). The sign in Fig. 1 advises everyone, including researchers, of danger if wading to collect BMIs near and below the large dam because of sudden fast discharge at various times to generate electric power. Fortunately, USA research scientists have a lower incidence rate (near 1%) for scuba dangers than other countries' research scientists (Dardeau and McDonald 2007), who make more mistakes during deep dives at $\geq$ 30 m, e.g., Japanese divers (Miyanishi et al. 2006). According to Efrig (2017), a medical doctor who practices stress management prevention, most people hesitate to think about danger prevention until it is too late to make corrections. However, the discussion section explains what the FW BMI researcher should do to avoid unnecessary stress and dangers.

I evaluated papers in six peer-reviewed journals and other background literature on ecology of FW BMIs to determine if dangers were reported or a warning was included. I discovered that many papers sparsely informed the reader of potential dangers in FW BMI habitats. The danger features and safety concerns found became the objectives of this paper. The objectives were to: 1) find and discuss hidden-dangers in papers that did not warn of existing dangers in the field sampling process, 2) determine if those danger factors with metric threshold values (toxic and hazardous chemicals), non-metric

Fig. 1. Warning sign on approach to river below a spillway of large dam.

dangers (e.g., caves with aquatic habitats), could be documented, 3) determine frequency of danger occurrence, 4) compare baseline values (safe) to above baseline and extreme (unsafe) values, 5) present practical and innovative safety recommendations to avoid dangers and fatalities prior to and during BMI surveys to enhance researcher safety. Examples of important government agencies that furnish water safety data and services to the public are presented here and in Table 1. The U.S. Environmental Protection Agency (USEPA) established the National Primary Drinking Water Regulations (also termed Standards) (USEPA 2017a). These Standards specify maximum contaminant levels (MCLs) with specific limits for drinking water contaminants to protect human health and are legally enforceable. Also, USEPA set Secondary Drinking Water regulations with secondary maximum contaminant levels (SMCLs) that are not federally enforceable or considered a threat to public health (USEPA 2017b). SMCLs are regulated mainly because of poor aesthetic water quality (e.g., metallic taste, odor, color, etc.). In addition to primary and secondary drinking water regulations, the Standards include states, U. S. Territories, and tribal lands (USEPA 2018). The USA drinking water and recreational water are also protected from pollution and degradation of discharges from municipal and industrial wastewater treatment plants into navigable water by the Clean Water Act (USEPA 1972). The U.S. Geological Survey (USGS 2017) researches water quality in states and U. S. Territories and reports stream flow and aquatic data in real-time from gaging stations by satellites. The Commission for Environmental Cooperation (CEC 2011) was a multi-year effort by Canada, Mexico, and the USA government agencies that developed and published North American Terrestrial Ecoregions—Level III. Each of the above countries described their ecoregions similarly by location, climate, vegetation, hydrology, terrain, wildlife, and land/human use. The regions relevant to this paper are listed in Table 1 concerning baselines and danger factors in USA Ecoregions (Wiken 2011a, b, c, d). Low precipitation included: a) Warm desert, b) Cold desert, c) Steepes, and d) as compared to High precipitation. The U.S. Centers for Disease Control and Prevention (USCDC 2015), sets pH, chlorine and other safety ranges. The U.S. Coast Guard (USCG 2017) presents annual statistics on water and boat related fatalities and accidents and issued the 2016 annual statistics report on inland waters (USCG 2017). This inland report compiles water statistics from data on rafts and boats and combines statistics with the states, U. S. Territories and media reports of recreational waters for related accidents, fatalities (that include drowning), and causes.

Table 1. Fourteen baseline metric values compared to exceeded metric values and extremes in freshwater ecosystems when collecting benthic macroinvertebrates as given in citations.

Danger factors	Baseline metric values	References 1	Excessive metric values[2]	References[1]
1. Chemical hazards	Selenium (Se):	USEPA 2017a 0.05 mg/l	Se: 0.58 mg/l	Merriam et al. 2011
	Iron (Fe): 0.3 mg/l	USEPA 2018	Fe: 31.0 mg/ l	Lencioni et al. 2012
	Nitrate NO3: < 10 mg/l	USEPA 2017a		
	Sulfate S04: 3–10 mg/l	Davis 1980c	S04: 1,725 mg/ l	Davis 1980b
	Dissolved oxygen: Class 1: >9.5 mg/l[3] Class 2: ≥ 8.0 mg/l[3]	USEPA 2018	O2: 0.29 mg/l	Tobler et al. 2006
2.Temperature (Hot)	25-28◦C (77-82°F)	Olympic swimming pool 2019	54◦C ~ Human scald point	PSEG 2017
			42°C Sinkhole bottom water	Bednarz 1979
(Cold)	In open water wetsuit required if < 18°C	Olympic open water 2019	0–14°C Extreme cold	NCCWS 2017
			0–14°C Scuba dives	Rennie and Evans 2012
3. Discharge	1.0 m3/sec	Gore 2006	≥ 937 m3/sec	Blinn et al. 1995
4. Maximum wade depth	0.4 m[4]	McDowell et al. 2008	~ 0.6 to 1.5 m	Barber and Minckley 1983
5. pH (Low)	6.5 neutral	USCDC 2015	pH: 3.2	Smucker and Morgan 2011
(High)	8.5 neutral	USCDC 2015	pH: 10.3	Davis 1980b
6. Low precipitation (Warm desert)	50-900 mm/yr Mojave Desert	Wiken et al. 2011a	50 mm/yr Death Valley area, CA	Wiken et al. 2011a
(Cold desert)	800-2,000◦C Aleutian Islands, Alaska, Southern Arctic	Wiken et al. 2011b	100–150 mm/yr Tundra, n Northern Arctic	Wiken et al. 2011b
(Steepe)	518 mm/yr	Wiken et al. 2011c	300 mm/yr	Barber & Minckley 1983
7. High precipitation	2,500 mm/y Eastern Cascades, WA-CA	Wiken et al. 2011d	3,397 mm/yr	Rosser & Pearson 1995
8. Turbid	Maximum: 1 NTU/ sample or any month 95% of samples < 0.3 NTU	CCWP 2015	NTU: 450	O'Neill and Thorp 2011
	NTU not to exceed: 5.0 for non-conventional filtration and field	USEPA 2017a	NTU: 450	Rosser and Pearson 1995
9. Gradient	≤ 4%	Charlebois and Lamberti 1996	33%	Wallace et al. 1995

(Continued on next page)

Table 1. (Continued).

Danger factors		Baseline metric values	References[1]	Excessive metric values[2]	References[1]
10. Sewage		Heterotrophic plate count is acceptable if the count is < 500 colonies per ml	USEPA 2017a	1,000 colonies/ 100 ml sample	Dewailly et al. 1986
		BOD5: < 1.0 mg/l (pristine)	Chapman 1996	BOD5: 7.2-9.7 mg/l	Hoang et al. 2010
11. Electrical conductivity (EC)		EC: 4.6 µS/cm 2010	Luoto et al. 2013	EC: 1,255 µS/cm	Hartman et al.
		EC: 358 µS/cm	Davis 1980c	EC: 11,500 µS/cm	Davis 1980b
12. Wind effects on boats	small ≤ 6 m	Light breeze: 1.6-3.3 m/s, > waves 0.2 m high	Beaufort scale = 2 Beaufort scale 2017	Gentle breeze: to 5.4 m/s, ≥ waves 0.6 m high	Beaufort scale = 3 : Beaufort scale 2017
	large ≥ 21 m	Moderate breeze: 4.0 m/s > waves 3.0 m ht	Beaufort scale = 4 Beaufort scale 2017	Near gale: 13.9-17.1 >waves 4.0 m high	Beaufort scale = 7 Beaufort scale 2017
13. High altitude		≤ 2,424 m (8,000 ft)	Rock 2002	3,538 m asl	Finn and Poff 2011
				3,200 m asl .	Heinhold et al. 2013
14. Total dissolved solids (TDS)		TDS: ≤ 245 mg/L	Davis 1980c	TDS: 3,811 mg/l	Canton 1982
				TDS: 9,000 mg/l	Barber and Minckley 1983

[1] References are listed in literature cited
[2] Exceeds USEPA primary contaminant level and/or baseline metric safety limit from authorities in citations. Unmarked USEPA chemicals are baseline secondary contaminant maximum levels.
[3] Class 1 standard is extraordinary water quality for drinking, domestic, and agriculture use. Class 2 standard is for excellent water quality for drinking, domestic, agriculture and fishery (salmon) migration.
[4] Researcher to adjust height to fit the equivalent of 0.4 m safe wade depth limit see Methods section.

Many water accidents and drownings occurred in swift streams and rivers after spring rains and snow melt when discharge exceeded tolerance for aquatic researcher survival, especially when combined with low-head dams (Tschanz 2015). This seasonal trend occurred in states subject to intense precipitation in regional and mountain areas (Short and Ward 1980, Jacobi and Cary 1996), in fast tributaries of the Great Plains (Gray et al. 1983), and internationally such as the Shinano River in Japan (Kobayashi et al. 2013). Drownings also often occurred in streams and rivers and near low-head dams after spring melt through summer due to hidden hazards (Tschanz 2015). However, no accidents occurred at Alabama mill dams (low-head dams) in 20 streams with intact (unbroken), relic (broken and no spillway), and breached (some footings remained) low-head dams studied for fish assemblages in shallow water (mean depth ranged 0.16 – 0.50 m) (Helms et al. 2011). In a separate Alabama study of mollusks assemblages in 22 other small, low-head mill dams (height < 10 m), no accidents occurred by wading, snorkel, and scuba used in deeper sections (mean depth > 1.0 m) (Gangloff et al. 2011).

Materials and Methods

The selection of journals was partly from a list of 22 journals in FW aquatic ecology (Feminella and Hawkins 1995) and similar journals accessed mainly on-line, and the Colorado State University library.

The prioritized features were: 1) well-edited research papers, 2) papers recognized by indexing research engines (e.g., Web of Science and others), 3) papers on field ecology, FW BMIs including aquatic insect vectors, natural history, and conservation, and 4) papers from USA, regional, national, and international areas. The selected journals met each of the above priorities but varied by geographical emphasis of research in three areas: USA regionally, (e.g., Wiken et al. 2011a, b, c, d), nationally, and internationally). Journals selected that met the priorities were: Annual Review of Entomology (AREnt), Journal of Freshwater Ecology (JFWE), Journal of the North American Benthological Society (JNABS) (renamed as Freshwater Science (FWS) in 2011), The Prairie Naturalist (PrNat), and The Southwestern Naturalist (SWAN).

Referenced journals, their citations, and prominent textbooks (e.g., Rosenberg and Resh 1993, Hauer and Lamberti 2006, Merritt et al. 2008, Thorp and Rogers 2015) were consulted.

I counted danger factors listed in Tables 2–4 by items per paper of journals, such as, lotic habitats (flowing waters) and lentic habitats (non-flowing waters), caves with aquatic habitats (Howarth 1983; Howarth and Stone 1990; James 2010; Tobler 2006, 2013), cold flowing waters (0–14°C) (Short and Ward 1980, Lencioni et al. 2012, National Center for Cold Water Safety (NCCWS 2017), and hot springs (few aquatic insects have adapted to exceed 39-42°C) (Bednarz 1979, Ward and Kondratieff 1992, Nolte et al. 1996, Alexander et al. 2011). Lotic water included discharge below dams and lentic water included marshes, lakes, and impoundments, e.g., reservoirs of dams. Large and small boats were counted with reference to size, currents, wave height, wind speed, and heavy and light water samplers. I counted tributaries that increased in discharge from precipitation and snow melt. Counts included insect vectors (Culicidae: *Anopheles gambiae* Giles complex) (Takken and Knols 1999) and dangerous animals (Courtenay et al. 2012). Drinking water contaminants and their frequency per site were counted. The extensive Standards contained a longer list of hazardous chemicals than in the examples (Table 1, item 1) of the MCLs for drinking water. Examples of drinking water contaminants with hazardous and toxic chemicals in the Standards were: 2-4-D and lindane, herbicides (diquat), inorganics (e.g., antimony, cadmium, lead, mercury, and selenium), disinfectants (chlorine), fumigants, pharmaceuticals, nitrates, and radionuclides (including radium and uranium), etc. In addition to the Standards, chemical contaminants were named and cited by authorities. (e.g., scientists with expertise in FW Ecology, BMIs, and in government regulatory agencies presented in Literature Cited). Of 15 SMCLs, several examples are given in Table 1 with baseline values: iron, Fe: 0.3 mg/l, sulfate: SO_{4}: 250 mg/l, and total dissolved solids, TDS: 500 mg/l (USEPA 2017a) and high and low extremes by authorities. Photos of dangerous large and low-head dams were accessed from an interactive database (Hotchkiss et al. 2014).

Shallow water samplers to study BMIs on substrate were mostly conducted with only a few of many types of available standard samplers e.g., Surber, to depths of 0.3 m, Hess to 0.5 m, D-frame to 0.3 m, kick net or Stanford-Hauer kick net from 0.2 to 1.0 m, (Surber 1937, Barbour et al. 1999, Hauer and Resh 2008, Merritt et al. 2008). No definitions were found in the literature on shallow water samplers related to human height or gender concerning wade depth limit for safety. However, a large statistical study in physical anthropology included age, race, ethnicity, gender, and height measurements (McDowell et al. 2008). A data summary of this work included: males 20 years and older: n = 4,482, $\bar{x}$ ht = 176.3 cm, SE = 0.07; for females 20 years and older: n = 4, 857, $\bar{x}$ ht = 162.2 cm, SE = 0.06. Here, I propose a method to apply the statistical data (McDowell et al. 2008) of height and means per gender to compare with researcher height and to obtain a safe shallow water wade depth. Also, I explain how to apply the means to prepare for safe wades. For example, the mean height for males was 1.76 m (or 176 cm in the above data summary) and if he works any of the standard samplers except the kick-net, due to his height he will be safe at 0.4 m. The same sampler depths safe for the male would be safe for the female at a mean ht of 1.62 m. However, for deeper kick-net wades up to 1.0 m, the male would be safe even if he stepped into a hole up to ~ 0.4 m (up to his hip in water). For the same female, her height would be unsafe (0.4 m for sampler + 0.4 m for a hole) and she would be in deeper water relative to the male at 0.8 m.

If river depth is unknown, the researcher should assess depth with numbered metric wading staff, or with a 1.0 m ruler, or consult USGS (2017) for ~ depth and velocity/river. The above samplers were designed for shallow streams and rivers with mostly cobble, gravel, and sand mixed substrate (e.g., Barbour et al. 1999, Hauer and Resh 2008, Merritt et al. 2008,) and were relatively uniform across channel width minus protruding objects (Gore 2006). Risk usually includes streams with combinations of dangers, e.g., collecting in a deep riffle (0.65 m) with swift currents (0.72–1.40 m/s) with substrate gravel and large cobble (Kobayashi

Table 2. Frequency of 28 freshwater danger factors, habitats, and event counts of safety concern to researchers in papers from reviewed journals with most total per journal given from top down.

Danger factors with metric values and non-metrics		Number of Events in Journal Papers[1] PR NAT	SWAN	JNABS	FWS	JFWE	AAREnt	Total
1. Lotic water habitats (e.g., flowing rivers, streams, springs, and aquifers)		38	208	310	196	85	406	1,243
2. Unlisted dangers (e.g., shifting river substrate sands)		30	71	295	240	70	281	987
3. Chemical water hazards (e.g., pesticides, nutrients, gases)[2]		49	77	140	143	105	313	827
4. Impoundments	Dams	10	24	55	24	19	29	
	Total	19	56	161	153	54	220	663
	Reservoirs, lakes, pools	9	32	106	129	35	191	
5. Temperatures of Cold	Cold	27	47	174	94	57	189	
$\leq$ 0–21ºC & Hot $\geq$ 40ºC [b]	Total	27	50	176	95	57	229	634
	Hot	0	3	2	1	0	40	
6. Substrate hazards [3]		45	52	152	171	75	61	557
7. Discharge ~1m3/s[2]		6	51	113	54	23	131	378
8. Dangerous animals and insect vectors		2	7	0	3	7	286	305
9. Exceeded maximum depth of 0.4 m[2]		17	5	134	42	60	5	263
10. Boats, cables, grabs, nets, seines[4]		45	57	27	26	62	25	242
11. Floods & Flash floods per study		18	24	25	47	10	88	212
12. Total pH $\leq$ 6.5 – $\geq$ 8.5[2]	High	8	20	38	14	12	21	
	Total	8	25a	49	58	18	43	201
	Low	0	5	11	44	6	22	
13. Low precipitation $\leq$ 500 mm/y (e.g., deserts, Steppes, Tundra)[2]		3	37	18	36	9	81	184
14. High precipitation > 2500 mm/yr[2]		3	22	15	6	9	114	169
15. Marsh, swamp, bog		6	11	7	5	6	129	164
16. Night & twilight in aquatic habitats		17	10	10	5	22	81	145
17. Turbid water $\geq$ 5 NTUs[2]		12	27	43	24	23	5	134
18. SCUBA/Snorkel swims, dives with wide range of depths, time underwater, discharge, distance, and temperature		0	13	86	13	7	1	12
19. Gradient $\geq$ 4 % m/km[2]		0	8	42	48	6	10	114
20. Sewage $\geq$ USEPA test limit of total/fecal coliform/MPN, BOD[2]		0	10	27	7	19	34	104
21. Conductivity 400 µS/cm[2]		9	26	39	7	9	7	97
22. Caves with aquatic habitats (e.g., streams, waterfalls, & seeps)		0	35	12	2	0	46	95
23. High physical effort (e.g., collect near hazardous dams/swift tailwaters, in deep sinkholes)		7	16	21	16	8	14	82
24. High winds > 3-5 m/s (8-12 mph)[2]		16	5	5	2	5	39	72
25. High altitude $\geq$ 2,425 m (8000 ft)[2]		0	25	11	3	1	30	70
26. Many sampling sites $\geq$ 40		1	7	7	14	5	16	50
27. TDS $\geq$ 500 mg/[2]		0	34	0	0	4	2	40
28. Waterfalls		0	5	3	4	1	16	29

[1] Abbreviations from complete journal titles given in Table 4.
[2] Exceeded USEPA primary contaminant level or metric baseline safety limit from authorities in citations.
[3] Substrate physical hazards: Sharp metal, glass, ice, rocks, holes, roots, snags, algae with mucus, stumps, vascular plants, etc.
[4] Boats: small, e.g., canoe in swift currents, waves to 0.6 m; large boats with large net, grabs to trawl deep water, e.g., $\geq$ 21 m, waves to 4 m.

et al. 2013), and increases in cold water with a slippery substrate (Wellnitz et al. 1996).

Reviewed papers were excluded if: 1) they were ambiguous, 2) BMIs were not resolved at least to family to be of value as a bioindicator and for BMI vector surveys (Rosenberg and Resh 1993), 3) BMIs were not identified from a natural, FW habitat by location and date, 4) the author or co-author never entered the water in a survey of a FW habitat, 5) BMIs were < 1.0 mm, 6) study was speculative, 7) specimens were petrified fossils, 8) data were not original. Two papers (Hotchkiss et al. 2014, Kern 2014) were exceptions to above exclusions in this review because of a timely civil engineering thesis on low-head dam dangers, an interactive database and practical solutions to prevent accidents in drownings.

If authors indicated moderate or high turbidity, swift discharge, or slippery waterfalls, their professional judgement was accepted. Aircraft were considered equivalent to boats in deep, swift water Paragamian (2010) as potentially dangerous. Helicopters and a few fixed winged aircraft that were deployed in early eradication projects over African fast streams and rivers (Davies et al. 1962), with pesticides applied at spillways of large dams and in rapids (Davies 1994) were included. Helicopters utilized in difficult to access locations such as the Mackenzie River, its tributaries, and Canadian wetlands (Scott et al. 2011) were also included.

The term, unlisted dangers, is defined here as an infrequently occurring and non-metric danger (e.g., sinkhole at cave entrance, Howarth 1973), collections below high hazard dam (Davis 1980b), runaway barges on large rivers and shifting bottom sands (Way et al. 1995).

In Table 3, non-metric danger factors were not ranked because they vary with conditions, including slippery substrate, thin ice over streams and ponds, obscured deep holes in rivers, underwater snags, stumps, and unique events (e.g., a cave passageway with a surprise flood or rockslide). Other dangers possibly overlooked by researchers: barbed wire on substrate of shallow, turbid streams, sloughs, and lakes (RDS unpublished).

Table 3 presents examples of a safe stream with few dangers in the Devil's River, Texas --- a clear, riffle bearing stream with springs, intermittent pools, low waterfalls, limestone substrate, excellent water quality, and high BMI diversity (Davis 1980c). In Table 1, baseline studies were presented first with safe low metric values and compared to metric highs and extremes as examples of contrast in collection safety.

Open the following web address (at the BYU website) to access the USA low-head dam interactive database (Hotchkiss et al. 2014) with a color map of the states showing one or more fatalities at these structures http://krcproject.groups.et.byu.net/browse.php The reader can see the total fatalities recorded was 555 from 276 sites. This information was found by accessing the above website on 19 December 2018, as shown on the colored map of 39 state locations with submerged fatality points at intact dams. New incidents may be reported by clicking the tab on top of the color map page (Hotchkiss et al. 2014).

Results

Six refereed journals in Table 4 containing 2,075 papers were reviewed for field research resulting in 505 FW BMI papers and of these, 265 (52%) contained danger. However, the above 505 journal papers reported only 90 (18%) with danger.

Extreme high and low frequency totals per journal were reported in Table 2. The most reported frequency total for combined journals with danger that exceeded other metric threshold values was lotic waters with a total of 1,243. The most common non-metric danger near the top of Table 2 with most reported dangers was unlisted dangers with a total of 987. Of the lows with three reported zeroes per journal, TDS (metric) included a total of 40. The least reported low per journal was waterfalls (non-metric) with a total of only 29. Each of these extreme highs and lows were explained in the discussion.

Of the 14 metric dangers listed in Table 2, only 12 represent one metric danger value. However, when the two other danger factors, were included (e.g., chemical water hazards and sewage effluents), they account for the total 14 metric values. Sewage involved several required microbiological and chemical tests to express their values (e.g., total and fecal coliform counts per sample and biological oxygen demand (BOD_5) in mg/l). For a complete list of chemicals with safety thresholds for drinking water quality, the Standards should be consulted in addition to examples in Table 1, for any of the above test groups.

The 14 non-metric danger factors may be considered on a large scale with examples reported by specific location and other features. Some examples were: low-head dams with a history of multiple fatalities, unmanaged old dams, remote caves that flood, deep caves with difficult access and exit, and remote waterfalls especially slippery during high seasonal flow (Holzenthal 1995).

In 2016 the US Coast Guard reported 437 drownings for recreational boats and 10 drownings at dams and locks in states and U.S. Territories, but did not mention low-head dams. However, low-head dams have recently been recognized as a public danger, mainly due to the Kern thesis and were included in this paper because of the high drowning rate and increase in fatality postings on the interactive database. Recent statistics from the interactive database with 89 photos of dams (Hotchkiss et al. 2014) were accessed on 19 December 2018 by RDS. This database indicated that low-head dams in 39 states accounted for 555 drowning fatalities, the number of fatality sites was 276, and had a maximum of 12 fatalities at a single site. Photos of 84 intact low-head dams were on streams and rivers, and photos of 15 large dams with locks were on rivers in the above database where drownings occurred.

Discussion

To my knowledge this may be the first paper to find, document, and discuss danger factors were mostly unreported in the FW ecological research and imperiled researcher safety. This paper originated after an inquiry to determine if six peer reviewed journals reported the occurrence of danger together with their subject matter in FW ecological field research of BMIs. This inquiry led to the objectives of this paper with some new and surprising and results and recommendations to enhance FW researcher safety. Beginning here is an overview of five objectives that confirm 28 dangers were found.

In objective one, hidden dangers occurred, but few (18%) were reported or presented a warning to the reader. However, 52% of the journal papers contained dangers (Table 4). The sparse journal information on unreported danger implies that FW researchers may have depended on swimming ability, experience, and other information to avoid danger. However, some researchers are: unable to swim, inexperienced, or had minimal safety training, and some dangers are hidden and difficult to anticipate or have a deceptive calm appearance (e.g., low-head dams). Examples of the danger factors involved were from a wide range of sources in addition to the journal papers such as prominent textbooks (Hauer and Lamberti 2006, Merritt et al. 2008, Thorp and Rogers 2015), and research scientists in the Literature Cited section (Howarth 1983, Lencioni et al. 2012, Mebane et al. 2012, Kern 2014, and many others).

The image of a warning sign in the Introduction illustrated how some states warn public waders of swift currents and rising water level danger below hydroelectric dams. Some states advise of danger on-line and post warning signs to boaters upstream of low-head dam hazards at portals to prevent fatalities.

In objective two, hidden dangers caused accidents and especially drownings fatalities that were traced to metric threshold values (e.g., chemical hazards) and non-metric dangers (e.g, caves with FW habitats and or night collections in water) from field results and cited papers. However, only one mention of a scientific researcher was found as an example of extreme risk in deep (dives > 30 m) (Miyanishi et al. 2006). Some other examples of taking high risks include investigations in remote, deep caves with water hazards (Howarth 1973) and toxic gases (Howarth and Stone 1990, James 2010), deep arctic lakes (Luoto et al. 2013), desert sinkholes (Bednarz 1979, Macanowicz et al. 2013). Hidden dangers that involved fatalities were reported mainly at intake points upstream near large dams and below the dam release points for high discharge near and downstream of spillways, but most drownings occurred at low-head dams (Tschanz 2015). Videos and many photos of low-head dams and larger dams identified danger and drowning points seen on an interactive database and map of 39 states was revealed by the thesis in civil engineering hydraulics (Kern 2014). One of the most inconspicuous and deadly hidden dangers is low-head dams. Waders that venture on the dam and swimmers and boaters, canoers, and kayakers that flow over the dam were found trapped in a strong reverse backflow currents and in turbulence near and downside of the dam according to Kern (2014) and Tschanz (2015).

Several danger factors such as scuba and caves with FW BMI habitats may be metric or non-metric dangers depending on danger intensity, e.g., zero oxygen level in a scuba air tank if in deep water or in a deep cave. However, scuba dives in deep water were few and the exception. Also, the large caves of Mulu (Indonesia) and Undara (Australia) had challenges minimized because of carefully planned expeditions with experienced cave scientists, new and more precise technological equipment to map and report data, and required permits that specify conditions to explore, collect specimens, and include regulated time limits by country officials.

Data that supports important conclusions on hidden dangers originated in Table 4. Three examples show that Table 4 presents a wide range of data from the six reviewed journals but, requires some interpretation. For example, on inspection of row 3, column 3, it shows the journal with the

Table 3. A list of the 14 non-metric danger factors identified with cited references, examples, and locations.

Non-metric danger factors	References	Danger factor	Location
1. Lotic water habitats, e.g., river, streams, and springs (Partly metric)	Blinn et al. 1995	Collected benthos in substrate below large dam in fast current and 25 km downstream at 6.8 m depth by snorkel and scuba	Colorado River at Glen Canyon Dam and Lees Ferry, AZ
	Naiman 1979	Death Valley drying spring with slow flow	Near Tecopa, CA
2. Unlisted dangers	Way et al. 1995	Collecting in river, with heavy barges, and in shifting river sands to set and retrieve BMI underwater traps by scuba	Marshalls Point Mississippi River, MS
	Macanowicz et al. 2013	Accessed sinkhole with groundwater and steep sides (90° angle)	Bitter lake, NWLR, NM
3. Impoundments e.g., Dams and lentic waters e.g., reservoirs, lakes and pools	Adams 2011	Collect crayfish downstream and near old, remote, unstaffed dams and impoundments	Upper Little Tallahatchie River, sub-basin, northern MS
	Davis 1980b	High hazard dam seeping saline water	The upper Pecos River, TX
	Kern 2014	Author developed interactive database of fatalities at low-head dams in USA states with details and many photos	See authors database under Hotchkiss et al., 2014 in literature cited and click on hypertext
4. Substrate/physical water hazards[1]	Helms et al. 2011	Relic low-head mill dams with scattered concrete pieces mixed in substrate	20 old mill river sites in AL
	Wellnitz et al. 1996	Slippery rocks on biofilm	High altitude stream, St. Louis Creek, Rocky Mt. National Park, CO
5. Dangerous animals and insect vectors	Davies et al. 1992, Davies 1994	Vector control of *Simulium damnosum* complex an important vector of onchocerciasis or river blindness disease	Rivers, falls, rapids of East and central Africa
	Takken and Knoles 1999	Surveys of *Anopheles gambiae* complex and important malaria vector	Sub-Sahara, Africa and Arabian Peninsula
	Townsend et al. 2012	Crocodile slide at field site	Darby River, tropical Australia
	Waidt et al. 2013	Electric eels collected in mud flats and marsh with electro-shocker, and in float traps at night to 2 m depth	Hannacroix Creek, a tributary to Hudson River, NY
6. Boat size, wave heights, nets, sampling, grabs, etc.[2]	Macanowicz et al. 2013	Enter desert sinkholes, walls top to bottom at a steep angle	Bitter Lake NWLR, NM
	Schoenebeck and Brown 2010	Night collection by boat with heavy sampling equipment, e.g., grabs, cables, and long nets	Lake Cochran and Lake Madison, SD
	Way et al. 1995	Boat, cables, and winch to guide concrete blocks by scuba, on river substrate	Marshall's Point, Mississippi River, MS

(Continued on next page)

Table 3. Continued.

Non-metric danger factors	References	Danger factor	Location
7. Floods and Flash floods	Barber and Minckley 1966, 1983	Sonoran Desert flash floods at macrobenthic stream sites	Araviaca Creek, AZ
	Fisher 2011	Missouri and Yellowstone rivers flood rate studies	McKenzie Co., Northwest ND
	Gray 1983	Spring flash floods from snow melt in headwater streams of collection sites	Piceance Basin, CO
	Howarth 1973	Danger occurs when lava cracks release floods from surface rain and irrigation water into passageway	Lava tube on Island of Kauai, HI
8. Marsh, swamp, bog	Batzer and Wissinger 1996	Study of population and community ecology in large wetlands including insect vectors	From Newfoundland bogs to Everglades, FL
9. Night and twilight in aquatic habitats	Fisher 2011	Night micro-crustacean surveys at seasonal river pulse	Missouri and Yellowstone rivers in northwest ND
	Kershner and Lodge 1995	Night crayfish census	Northern Lakes, WI
10. Scuba/snorkel dives[3]	Hovarth et al. 1996	Snorkel-scuba dives: 6 lakes and 38 streams to find zebra mussels dispersal and populations	St Joseph R., IN and MI
	Vaughn and Taylor 1999	Snorkel and scuba dives in reservoirs and river census of clams for ecological status	Little River (tributary), dam areas, and main stem of Red River, OK
	Wisniewski et al. 2013	Strenuous snorkel dives against current to search for glochidia on rare fish in sharp rock crevices	Flint River, GA
11. Caves and their aquatic habitats (Partly metric event)	Howarth 1983 (cite #64)	Pioneering study of troglobites in 50 lava tubes	Kauai, Hawaii, Maui, Oahu Islands, HI
	Howarth and Stone 1990	First troglobite arthropod community study in deep cave with high humidity, high CO2, level 200% more than ambient air outside entrance and zero level O2 at 830 m inside.	Bayliss is largest cave of Undara volcano lava tube complex, Queensland, Australia
12. High physical effort	Charlebois and Lamberti 1996	Extensive snorkeling and swims to monitor effect of invasive crayfish consumers of BMIs and periphyton	Middle Branch, Ontonagon River, MI
	Fisher 2011	Missouri and Yellowstone rivers flood rate studies	McKenzie Co., ND
	Ozersky et al. 2011	16-year Scuba monitoring at bottom of Canadian cold lake for zebra mussel ecology	Lake Simcoe, Canada
13. Many sampling sites ≥ 40	Larsen and Olden 2013	Conducted crayfish census at 100 lake sites.	Puget Sound lowlands, WA
14. Waterfalls	Charlebois and Lamberti 1996	Bond Falls	Ontonogon River, MI

[1] See list of substrate physical hazards at bottom of Table 2
[2] See list of boat size, wave heights, nets, sampling grabs, etc. at bottom of Table 2 and effects of wind velocity on boats in Table 1.
[3] See Discussion for explanation.

Table 4. Six journals reviewed for danger during collection of freshwater benthic macroinvertebrates.

Journal	Years	Total Papers Reviewed	Total Freshwater BMI* Papers	BMI[1] Papers with Implied Danger	Percent with Implied Danger	BMI[1] Papers with Reviewed Danger	Percent with Reviewed Danger
Annual Review of Entomology AREnt [2]	1983–2000 2011–2013	487	78	15	19	42	54
The Prairie Naturalist PrNat [2]	2005–2013	175	18	6	33	15	83
The Southwestern Naturalist SWAN [2]	1979–1984 2012–2013	773	71	14	20	37	52
Journal of Freshwater Ecology JFWEcol [2, 3]	2010–2013	246	117	20	17	62	53
Journal of the North American Benthological Soc. JNABS [2]	1995–1996 2011	190	110	22	2	56	51
Freshwater Science FWS [2]	2012–2013	204	111	13	12	53	48
Totals	46	2,075	505	90	18	265	52

[1] Abbreviation of BMI = benthic macroinvertebrate for this table.
[2] Journal abbreviations apply to Tables 2 and 4.
[3] In 2011 the Journal of the North American Benthological Society (JNABS) changed its name to Freshwater Science (FWS).

most papers was the second lowest in aquatic dangers (column 7). However, row 2, column 3 also shows that the journal with the lowest total papers surprisingly correlates with row 2, column 8 at 83% for the most danger papers per journal. This surprise result was because almost every paper submitted to the PrNat in the second case contained at least three dangers. However, the total number of dangers was gleaned from journal papers that required time consuming reads of text, tables, figures, and citations.

This paper included two innovative contributions from researchers. First the M.S. thesis below that identified dangers associated with low-head dams and presented solutions to correct this problem (Kern 2014). Second, an innovation (proposed by RDS) herein that FW researchers may use to evaluate their height by gender to means from a large database (McDowell et al. 2008) to prepare for safe wading when considering substrate holes and stream conditions. Researchers should know bottom depth and the conditions (e.g., substrate composition, water clarity, and current velocity). It is important to find wade depths up to 1.0 m so researchers know their height is ample for water depth and holes to 0.4 m depth or deeper before sampling substrate for FW MBIs.

In objective three, dangers were considered by frequency of occurrence. The frequency of occurrence for reviewed journals (Table 2) with dangers is explained here. Lotic waters were the most frequently reported metric partly because of many tributaries to streams and rivers and had the most citations of reported papers with danger (however, many were short term or less than a one-year study). Unlisted danger was the most reported non-metric with high frequency. Infrequent kinds of danger were experienced, sometimes resulting in a variety of incidents at one location (e.g., shifting bottom sands, and variable currents when scuba diving to place artificial substrates on river bottom during heavy barge traffic, deep scuba dives (≥ 30 m) (Miyanishi et al. 2006), wading across swift glacial streams (Orr 2017), collecting FW BMIs at or below hazardous, old, unattended, and abandoned dams (Davis 1980b, Adams 2013, Tschanz 2015). TDS reported the most zero values per journal and second lowest frequency. Many papers were on specifics unrelated to TDS (e.g., surveys for endangered species, bioindicators of water quality, insect vectors, and biocontrol releases). However, TDS may have many origins in springs, streams, and rivers (e.g., groundwater with nitrates, and limestone aquifers, excessive turbidity, and sewage) (Davis 1980a, b, c). Hot springs (metric) and caves with aquatic habitats (non-metric) were reported as tied because they had two zero values per journal. Few papers reported BMIs (especially insects) in hot springs if water exceeded 39-42°C because of the lethal effect to most FW BMIs (Table 1, item 2). AREnt and SWAN exceeded four other journals in reporting a combined total of 81 dangers in aquatic habitats of caves as a result of international surveys, including some Pacific island caves. Last reported were waterfalls because they had the fewest reported total frequency (non-metric) of any danger factor per journal. However, high waterfalls have common dangers that may lead to fatalities mainly because of slippery rocks in wet season (Holzenthal 1995) and may have treacherous, sharp rocks in dry or cold season, and require high elevation climbs. (Finn and Poff 2011).

In objective four, two danger groups considered equally dangerous for field safety, are explained here. The 14 non-metric dangers were identified as not having specific measurable values and may not be normalized because they are unique and have separate natural habitats such as caves, bogs, marshes, swamps, etc., (Table 3). Also, the non-metric dangers are characterized by their collective features (e.g., floods) and events (e.g., twilight). The 14 metrics included measurable baseline threshold values having maximum safety limits (or minimum for low temperature, precipitation, and pH) or if extended beyond baseline values they are unsafe as compared in Table 1 (e.g., MCL chemical contaminant levels of the USEPA).

In objective five, recommendations begin with acceptance of individual responsibility for adequate plans and preparation to complete safe FW ecological research studies that consider the presence of dangers. Effective plans should include early advice from a knowledgeable mentor. In general, field site safety and location are site dependent and subject to a wide range of variables (e.g., site access, habitat conditions, season, number of sites, and duration of study). Plan to have a colleague present for assistance and safety, advise a friend of when you will return and location of field sites, and plan for a means of escape at likely danger points. Also, researchers should keep to good physical condition for rigorous days of work requiring stamina and swimming ability pending research goals. Graduate students with inexperience in the field would be fortunate to have a mentor that is helpful and available for guidance such as site selection and timely feedback and advice on unique problems. Preparation includes ability to change plans for emergencies and unanticipated conditions (e.g., wading into a deep hole or drop off, slippery substrate rocks, sudden and severe weather changes, injuries, etc.). This also includes ability to apply first aid (and having a good first aid kit) and CPR in the field, having permission prior to the study from the owner or agency, required permits and following conditions, gate codes, and in cold climates have a change of clothes, towels, blankets, etc. to prevent hypothermia. Specific preparation should be adjusted to climate and project. Read the Texas River Guide to Safety (for lakes, rivers, whitewater, boats, rafts, clothing for cold water, good equipment gear, river hazards, spotting potential accident) in link below. below. https://tpwd.texas.gov/landwater/water/habitats/rivers/safety.phtml

In conclusion, hidden dangers were discussed considering the five objectives based on six peer reviewed journals and supporting literature. Sparsely reported dangers (or danger factors as a group) without a warning to researchers were discovered. The 28 danger factors were in two main groups: non-metric danger factors (e.g., caves with aquatic habitats) and metric danger factors with threshold values (e.g., stream discharge rates) and were documented. Danger factors were discussed by frequency of occurrence per journal papers and compared by totals. Safe baseline metric values were compared to those that exceeded the unsafe metric threshold values. Practical and common-sense safety recommendations were presented as guidance plans and preparation to protect FW researchers and others that enter the water (e.g., scientists, and aquatic recreationalists and the public) were presented.

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