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Feral guppies in Germany – a critical evaluation of a citizen science approach as biomonitoring tool

Verwilderte Guppys in Deutschland – eignet sich Citizen Science zum Aufspüren invasiver Arten?

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Summary: Biological invasions continue to grow at a rapid rate, fuelling the need for effective and feasible biomonitoring approaches. Citizen science is an increasingly popular way of undertaking long-term and/or large-scale monitoring while simultaneously engaging people with science and scientific issues. In temperate regions, industrially created thermal pollution of freshwater systems provides suitable conditions for (sub)tropical neobiota to survive harsh winter months and establish populations. Here, we present a citizen science project designed to collect data on feral populations of guppies (*Poecilia reticulata*) and other ornamental fishes in Germany. So far, only one established population has been described for Germany, residing in the thermally altered Gillbach-Erft river system near Cologne. Yet, most thermal power plants use water as a cooling medium, thus increasing the probability that more thermally influenced freshwater systems (TIFs) exist across Germany. With our large-scale approach, we were able to identify two additional locations with non-native (sub)tropical fish currently established and compile more data on now extinct populations of *P. reticulata*. Further, we present evidence that – as in the case of the Gillbach/Erft – these phenomena are most likely very localized, as they are solely dependent on the presence of thermal refugia. However, we call for continuous monitoring of these TIFs, especially in the light of disease and parasite transmission to the native fauna.

Keywords: Thermally influenced freshwaters, citizen science, invasive alien species, non-native species, aquarium trade, thermal pollution, *Poecilia reticulata*

Zusammenfassung: Biologische Invasionen nichteinheimischer Arten nehmen weiterhin zu und verstärken damit die Notwendigkeit für effektive und praktikable Ansätze zur Überwachung und Aufzeichnung von Invasionsereignissen und -prozessen. Wissenschaftliche Bürgerbeteiligung, besser bekannt als ‚Citizen Science', bietet die Möglichkeit, langfristige und/oder groß angelegte Monitoringstudien durchzuführen und gleichzeitig Mitbürger in wissenschaftliche Themen und Problematiken einzubeziehen. In den gemäßigten Breiten führt das Einleiten von industriell erzeugtem warmem Abwasser in Flüsse und Bäche dazu, dass sich nichtheimische (sub)tropische Neobiota trotz der oftmals harschen Wintertemperaturen dauerhaft ansiedeln können. Hier präsentieren wir ein Citizen-Science-Projekt, das dazu entwickelt wurde, Daten über das Vorkommen von wilden Populationen von Guppys (*Poecilia reticulata*) und anderen Zierfischen in Deutschland zu sammeln. Bisher war nur eine Guppypopulation in Deutschland beschrieben, die sich im thermisch belasteten Gillbach-Erft-Flusssystem in der Nähe von Köln etabliert hat. Allerdings nutzen viele Kraftwerke Wasser als Kühlmedium und somit ist die Wahrscheinlichkeit hoch, dass mehr solcher thermisch belasteten Süßwassersysteme (TIFs) innerhalb Deutschlands existieren. Im Laufe des Projekts konnten wir zwei weitere Gebiete mit etablierten (sub)tropischen Fischen identifizieren und zusätzliche Daten über bereits ausgestorbene Populationen zusammentragen. Nach unserer Einschätzung sind solche Refugien – wie im

Falle des Gillbachs – höchstwahrscheinlich nur lokal begrenzte Phänomene, da sie von der stetigen Warmwassereinleitung abhängen. Dennoch fordern wir eine kontinuierliche Überwachung solcher Systeme, vor allem angesichts der Tatsache, dass die Übertragung von Erkrankungen und Parasiten auf die einheimische Fauna bereits vereinzelt nachgewiesen worden konnte.

Schlüsselwörter: Thermisch belastete Süßwassersysteme, wissenschaftliche Bürgerbeteiligung, invasive fremde Arten, nichteinheimische Arten, Zierfischhandel, thermische Belastung, *Poecilia reticulata*

1. Introduction

Invasive species are drivers of global environmental change (Sala et al. 2000; Clavero & Garcia-Berthou 2005; Schröter et al. 2005; Shvidenko et al. 2005; Butchart et al. 2010), which in its course is likely to drive even more new invasions (Walther et al. 2002; Parmesan & Yohe 2003; Rixon et al. 2005; Hickling et al. 2006; Britton et al. 2010). When managing non-native species, one of the top issues identified is a general lack of awareness and education (Caffrey et al. 2014; Piria et al. 2017). In fact, some non-native species remain undetected or are detected only after their successful establishment (e.g. Geller et al. 1997; Lohrer 2001). Control measures are most effective when intervening at an early stage of invasion, thus a timely detection and rapid response are pivotal to the success of most management actions (Bax et al. 2001; Cambray 2003; Copp et al. 2005a, b; Verbrugge et al. 2014). Monitoring efforts increase the chance of early detection (Myers et al. 2000; Bax et al. 2001; Lodge et al. 2006) and the collection of spatial and temporal information of species' ranges – native and non-native alike – are integral to this feat (Ricciardi et al. 2000). Yet, the intensity of biomonitoring approaches is often limited by the availability of funding and staff. Volunteer-based monitoring may be the only practical way to achieve the reach relevant to species' range shifts. Over the past decade, this type of citizen science (see Roy et al. 2012 for definition) has contributed greatly to the wealth of information available on spatial variation in colonization/extinction events (e.g. Rocha-Camarero & de Trucios 2002; Stohlgren et al. 2006; Eraud et al. 2007; Delaney et al. 2008; Crowl et al. 2008). In that, citizen science has proven effective in finding rare organisms, such as newly-arrived neobiota (e.g. 'Check, Clean, Dry', Invasive Tracers, SeaLifeTracker, AquaInvaders; see appx. 1) and disappearing native species (e.g. 'The Lost Ladybug Project'; see appx. 1).

The aquarium trade has been recognized as an important source for species introductions on a global scale (Padilla & Williams 2004; Duggan et al. 2006; Gertzen et al. 2008; Copp et al. 2010; Strecker et al. 2011; Maceda-Veiga et al. 2013; Kalous et al. 2015; Seebens et al. 2016; Zieritz et al. 2016; Lukas et al. 2017). A study investigating main pathways of introductions of freshwater non-natives in Europe showed that the release of pets was only second to aquaculture in terms of biological introductions caused (Nunes et al. 2015). Most released aquarium species have (sub)tropical origins and thus are unable to survive winter temperatures in temperate regions, such as Germany. However, as these thermal constraints start to diminish with climate change, the likelihood for non-natives to persist, establish and eventually spread increases (Rixon et al. 2005). In fact, some freshwaters already experience increases in water temperatures that are consistent with climate change projections due to thermal pollution (e.g. Rivers Mississippi, Rhine and Weser; Raptis et al. 2016). In the case of the River Rhine, richness and abundance of non-native species has increased continuously since the early 20th century (Leuven et al. 2009; Panov et al. 2009). Nevertheless, water temperatures in the Rhine can drop to below 4 °C in winter (e.g. January 2017 near Düsseldorf-Flehe; LANUV 2017) and thus most non-natives of (sub)tropical origin do not survive. Some often overlooked areas, where non-native species might survive the harsh winter months, are thermally influenced freshwater systems (TIFs, also termed thermally altered

aquatic systems (TAAS)). These systems are either heated by natural geothermal sources (e.g. Specziár 2004; Petutschnig et al. 2008; Piazzini et al. 2010; Milenkovic et al. 2013; O'Gorman et al. 2012, 2014; Sas-Kovacz et al. 2015) or due to anthropogenic activities (Langford 1990; Simard et al. 2012; Klotz et al. 2013; Cohen et al. 2014; Hussner 2014; Jourdan et al. 2014; Emde et al. 2016; Mulhollem et al. 2016; Lukas et al. 2017). Despite Germany's Renewable Energy Sources Act ("Energiewende"), thermal power stations fuelled by black and brown coal or nuclear energy are still abundant. Water is the standard cooling medium in thermal power plants, which take it in from nearby rivers and streams and in a once-through system return it to the natural environment at a higher temperature. Maximum discharge temperatures are assigned with the operation permit and are often based on recommended best practices. However, the prescribed maximum temperature difference of 3 K between water upstream and downstream of the discharge can be – and often is – exceeded due to permit exceptions (Rose, pers. communication 2017). Within their thermal range, these systems can provide suitable conditions for (sub) tropical neobiota year-round.

While TIFs exist throughout Germany, most studies analysing the distribution of non-native species exempt TIFs from their surveys (e.g. Wolter & Röhr 2010). So far, the stream Gillbach in the Rhine/Erft catchment is the only TIF with established non-natives in Germany that has been described in the scientific literature (Kempkes et al. 2009; Klotz et al. 2013; Jourdan et al. 2014; Emde et al. 2016; Lukas et al. 2017). The Gillbach is exclusively fed by a power plant's coolant water discharge and has received attention due to its established non-native species assemblage (e.g. *Vallisneria spiralis*, *Neocaridina davidi, Macrobrachium dayanum*, *Poecilia reticulata, Amatitlania nigrofasciata, Oreochromis* sp.*, Pelmatolapia mariae, Ancistrus* sp.; Höfer & Staas 1998; Kempkes et al. 2009; Klotz et al. 2013; Jourdan et al. 2014; Emde et al. 2016; Lukas et al. 2017). Among them are species like the guppy and several cichlids, all of which have a long invasion history all over the world (Welcomme 1988; Canonico et al. 2005; Deacon et al. 2011). The guppy exhibits particularly high propagule pressure (Lindholm et al. 2005) seeing that only one pregnant female is needed to establish a whole population (Deacon et al. 2011). Nevertheless, the Gillbach has been identified as a rather localized phenomenon with its (sub)tropical invaders being constrained by the temperature gradient, which is only maintained over a short distance (Klotz et al. 2013; Jourdan et al. 2014; Lukas et al. 2017). However, there are ecological consequences for the native flora and fauna (e.g. introduction of non-native parasites; Emde et al. 2016) that call for continuous monitoring of the Gillbach and similar systems. Outside of the scientific community, information of (sub)tropical species are circulating – whether it is the sensationalism of piranhas being landed by anglers capturing the headlines of local press (Anonymous 2007) or fish enthusiasts sharing video observations of feral aquarium fish found in local creeks (see appx. 2). Also, the aquarium magazine 'DATZ – Die Aquarien- und Terrarienzeitschrift' published several articles about the Gillbach (Kempkes 2002, 2005, 2011; Mendax 2011; Rose 2012).

Given the novelty of the idea that thermally influenced freshwaters serve as hotspots for non-native species (Gollasch & Nehring 2006; Emde et al. 2016) and the scarcity of knowledge we have about them, this study was designed to (1) investigate whether more thermal refuges for warm-adapted freshwater fish exist (or have previously existed) throughout Germany. This spatial and temporal baseline data could then be used to further instigate long-term monitoring efforts and management decisions. Further, we wanted to engage the public and (2) raise awareness for the issue of petfish release by aquarium hobbyists and its consequences.

2. Material and Methods

According to Pocock et al. (2014a, b) citizens are motivated to participate in science through interest, curiosity, fun or concern. Local naturalists and conservation organisations (e.g. The Nature and Biodiversity Conservation Union 'NABU') can easily be engaged, because they

already have a strong interest in invasive non-native species and the management thereof. Aquarium fish clubs and associations are equally aware of the subject. Ornamental trade is a main introduction pathway for non-natives (Padilla & Williams 2004; Emde et al. 2016; Lukas et al. 2017), so many clubs are educating their members that aquarium releases can be harmful to the local flora and fauna and are prohibited by Germany's animal welfare laws (§3 Abs. 3, 4 TierSchG). Further, some aquarists harbour a great curiosity for novelty strains, such as feral populations of guppies (fig. 1) and other ornamental fish, making them a great resource in terms of biomonitoring.

To reach our identified target audience, we approached four of the most widely distributed aquarium magazines in Germany with a proposal for a citizen science project. Our project was met with enthusiasm and three out of the four editors contacted published a small article stating our objectives and means of contact in their upcoming issues. Within a span of three months, our letter to the readership was printed in the 'Aquaristik Fachmagazin' [Oct/Nov 2016 (Lukas & Bierbach 2016a)], 'Amazonas' [Sep/Oct 2016 (Lukas & Bierbach 2016b)] and the 'DATZ – Die Aquarienzeitschrift' [Aug 2016 (Lukas & Bierbach 2016c)]. Each of these magazines has a print run of approximately 20,000, 15,000 and 3,500 copies, respectively. Additionally, our article was published in the newsletters of three aquarium fish societies [Association of German Clubs for Aquarium and Terrarium Care (VDA), German Society for Livebearers (DGLZ) and *viviparos* – the German Livebearer Working group]. We chose the guppy (*Poecilia reticulata* Peters, 1859) as an ambassador for our message

Fig. 1: Specimens of feral guppies retrieved from the Gillbach population in 2016. Both females (**A**) and males (**B**) show a great variation in live coloration, typical for fish of the ornamental trade.
Abb. 1: Guppys, die im Jahr 2016 aus dem Gillbach entnommenen wurden. Weibchen (**A**) und Männchen (**B**) zeigen ein großes Farbspektrum, typisch für Fische aus dem Aquarienhandel.

(also referred to as 'flagship species'; Veríssimo et al. 2011; Kalinkat et al. 2017), seeing that the species is very popular with aquarists, which is directly linked to its invasion success worldwide (Froese & Pauly 2017). As a visual stimulus, we included a picture of a pair of feral guppies obtained from the Gillbach in the letter. We quickly summarized the research previously conducted at the Gillbach and its implications for research on climate change and biological invasions. Further, we stated our objective to gather information about similar systems, which harbour non-native species in Germany. As a call to action, we asked readers to send in any information they might have on feral populations of guppies and other (sub)tropical fish via a mail address specifically activated for the project, associated with the Leibniz-Institute of Freshwater Ecology and Inland Fisheries. To further motivate readers and incentivise reporting, we advertised a prize draw of the popular aquarist books "Die Guppys" volumes 1 and 2 by Michael Kempkes (2010a, b). Participants were considered in the price draw, when their information was submitted to us via mail by November 30th, 2016.

3. Results

In total, we received eight replies – four were submitted before the end of the deadline and four additional reports were sent in afterwards (as of August 2017; see tab. 1) –, all of which varied greatly in detail and quality. We received GPS coordinates to two extant guppy populations in Germany: a thermal spring in Baden-Württemberg and a former coalmine in the Saarland, which has been turned into a water garden for tourism (see fig. 2). The site now includes a geothermal plant, whose discharge heats the water garden before being returned to the nearby creek at a more ambient temperature. Two participants verified the establishment of guppies in the Gillbach-Erft-system (see fig. 1). Another writer provided us with historical information of two sites: Wölfersheimer See and a power plant outlet near Kornwestheim. In the former, guppies and other neozoans such as goldfish, clown loaches, cichlids, suckermouth armoured catfish and turtles could be found until the early 1990s. Further, we did receive information of guppy occurrences in Australia

Tab. 1: Summary of feral guppy populations recorded in Germany. Adapted from observations compiled by Kempkes (2010a). Information received as a result of citizen science are indicated (CS).
Tab. 1: Zusammenfassung der in Deutschland aufgezeichneten, wilden Guppypopulationen. In Anlehnung an Ausführungen von Kempkes (2010a). Informationen, die im Zuge der Citizen-Science-Studie gewonnen wurden, sind gekennzeichnet (CS).

Location	Status	Reference
Gillbach and Erft (power plants Niederaußem & Frimmersdorf)	present	Höfer & Staas (1998); Kempkes, Rose & Budesheim (2009), Kempkes (2011); Jourdan et al. (2014); CS (see fig. 1 and appx. 2)
thermal springs near Bad Saulgau	present	CS
heated water garden near Reden	present	CS (see appx. 2)
power plant outlet near Kornwestheim	extinct (1980)	CS
Lake Wölfersheim (power plant Wölfersheim)	extinct (1991)	CS
Zerkwitzer Kahnfahrt (power plant Lübbenau)	extinct (1994)	Funda (1979); Paepke & Heym (2002)
outlet of power plant Trattendorf	extinct (1996)	Kempkes (2010; pers. communication Holm Arndt)
mine dewatering ponds between Sulzbach & Quierschied	extinct	Becker (1983); Meyer et al. (1985); Kempkes (2010; pers. communication Klaus Speicher)
mine dewatering ponds near Cottbus	extinct	Engelhardt (1993)
cooling ponds of power plant Espenhain	extinct	Arnold (1987, 1990)
thermal springs near Kaiserstuhl	unknown	Kempkes (pers. communication 2016)
Lippe (industry outlets near Dorsten)	unknown	Kempkes (2010; pers. communication Erich Meier)
Wurm (near Heinsberg & Frauenaurach)	unknown	Rogner (1981); Bernd (2003)
Braunschweig region	unknown	Bernd (2003)
Greifswald region	unknown	Bernd (2003)
Gundremmingen region	unknown	Bernd (2003)

Fig. 2: Map of Germany and the identified sites currently harbouring feral populations of (sub)tropical non-native fish. A total of four TIFs with extant populations of *P. reticulata* and other (sub)tropical fish taxa were identified (gray; tab.1). Further, populations that are known to be extinct (†) or whose status is unknown/could not be verified (?) are indicated.
Abb. 2: Deutschlandkarte und identifizierte Standorte, die derzeit wilde Populationen von gebietsfremden, (sub)tropischen Fischen beherbergen. Es konnten gegenwärtig vier thermisch belastete Gewässer mit Populationen von *P. reticulata* und anderen (sub) tropischen Fischarten identifiziert werden (grau; Tab. 1). Ferner sind ausgestorbene Populationen (†) und solche, deren Status unbekannt ist/nicht verifiziert werden konnte (?), aufgezeigt.

(1980s), Tanzania (1998) and Puerto Rico (current). Notably, one participant did specifically point out that no (sub)tropical fish species had established populations in any water bodies of Lower Saxony.

4. Discussion

The enactment of the legislation on the "Prevention and management of the introduction and spread of invasive alien species" (European Union 2014) poses an important milestone in the prevention of their establishment. Yet, the surveillance needed has to occur at spatial scales beyond the reach of ordinary research efforts. Citizen science provides the potential to collect data across much larger spatio-temporal extents than would otherwise be feasible. Rising in prominence (Silvertown 2009; Dickinson et al. 2012), citizen science covers a wide range of taxa (see Dickinson et al. 2010 for review). Among the most successful are targeted monitoring projects, where species are prioritized based on their taxonomy, endemic status, sensitivity to threats and/or public interest (Yoccoz et al. 2001). For example, citizen science data have enabled researchers to identify areas harbouring non-native birds in the continental United States and Hawaii (Stohlgren et al. 2006; Crowl et al. 2008). In Europe, thermally influenced freshwaters have been identified as hotspot for non-native fish species of (sub)tropical origin (Specziár 2004; Piazzini et al. 2010; Petutschnig et al. 2008; Milenkovic et al. 2013; Jourdan et al. 2014; Sas-Kovacz et al. 2015; Lukas et al. 2017). By engaging the public and asking people to participate in scientific research, our aim was to investigate how frequent these 'hotspots' are in Germany. When comparing print ratios (ranging from 3,500 to 20,000 copies) to the feedback we received (n = 8), the results of the survey were slightly puzzling. Several questions immediately arose:

(1) Are there no other sites with established (sub)tropical fish species? Judging by the amount of power plants currently employed that use water as a cooling medium, it is highly likely that more TIFs exist throughout Germany. In fact, the cooling ponds of some power plants are used commercially, rearing fish such as sturgeon, carp, tench, pike and pikeperch to take advantage of the elevated temperatures (e.g. power plants Jänschwalde and Biblis [closed 2009]; Klug 2009). However, the likelihood of (sub)tropical fish persisting remains low, seeing that a species must pass through a variety of environmental filters to become successfully established in a new habitat (e.g. Vermeij 1996; Williamson & Fitter 1996; Williamson 2006; Theoharides & Dukes 2007). In aquarium fish, the display of certain traits such as aggressive behaviour, rapid

reproduction, large size or illness increases the likelihood for intentional release by their owners (Padilla & Williams 2004; Duggan et al. 2006; Gertzen et al. 2008). Especially the former two can assist the success of establishment, but to survive fish must tolerate the environmental conditions at the introduction site. Even within a thermally influenced system, water quality can be an issue for stenoecious species. Further, they must succeed in acquiring critical resources and surviving interactions with natural predators and competitors. For example, the guppy population of the Zerkwitzer Kahnfahrt near Cottbus in Eastern Germany (tab. 1) persisted for about ten years before it broke down due to a combination of high predation pressure (most likely European chub (*Squalius cephalus*), established convict cichlids (*Amatitlania nigrofasciata*) and several avian predators) and an accident that caused the nearby power plant to shut down temporarily (Paepke & Heym 2002). In contrast, the reported population in the Saarland appears to be thriving (see appx. 2) and experience only moderate predation (introduced convict cichlids (*Amatitlania nigrofasciata*)). While this too seems to be a very localized system, we do recommend continuous monitoring due to its connectivity to a natural creek and the consequential threat of disease and parasite transmission.

(ii) Seeing that some TIFs harbour (sub) tropical fish populations, why did they not get reported? Blackmore et al. (2013) recommended in their Common Cause for Nature report to not only communicate the objective (why?) and methodology (how?) of a project, but also the consequences of the cause (then what?). Without a clear statement, organisers and volunteers might pursue different agendas (Nerbonne & Nelson 2004), e.g. participants may expect actions that are beyond the scope of the project or, in contrast, may face a scenario they find unacceptable. In light of pan-European bans for popular but invasive genera such as the apple snails *Pomacea* sp. (European Union 2012) or the marbled crayfish *Procambarus fallax* f. *virginalis* (European Union 2016), participants may fear that a detection of feral populations of aquarium fish will provoke similar legislative acts. As a matter of fact, the fact that we received a curious reply solely stating the absence of any feral fish populations in Lower Saxony may further support this hypothesis. Another potential explanation is that sites harbouring guppies are not easily accessible by the public. While many non-native species tend to invade highly modified habitats and thus end up in close proximity to the potential observer, on average, people are less likely to spend time around power plants for recreational purposes such as bathing or hiking. On top, power plant grounds are often enclosed by security fences, thus obstructing the access to TIFs that potentially contain non-native species. However, TIFs can be quite popular among anglers (e.g. Spigarelli 1974). An additional problem is that potential catchers such as motivated aquarists are legally hindered on catching fish without a valid fishing license and thus could only encounter potential feral populations of guppies as by-catch when seeking for natural feed for their pets (e.g. "Tümpelfutter").

Ideally, a trigger (= event prompting involvement) should neither be too common nor too rare to avoid participants feeling overwhelmed or disengaged (Pocock et al. 2014a,b). In our case, while spectacular, the trigger was most likely too rare, so that most people in our target audience simply did not possess the desired information. Lastly, motivation for the project could be lacking or the audience we engaged with was too narrow (see Grove-White et al. 2007). Successful projects may resonate with people for various reasons (see Pocock et al. 2014a,b) and in our letter to the readership we attempted to appeal to people's sense of place ("my area"), their pre-existing interest in fish (especially aquarium fish) as well as their sense of discovery ("I had no idea that feral guppies existed in Germany") and jeopardy ("My river might be under threat").

With hindsight comes insight, so (iii) how could we improve and structure future projects? Conservation enthusiasts and organisations with similar interests (e.g. naturalist societies, angling associations) have previously expressed concerns about sightings of invasive non-native

species, so could easily be engaged with recording them. Angling associations are already involved in citizen science, monitoring fish catches and stocking efforts (e.g. 'Besatzfisch', 'Digitaler Fischartenatlas'; see appx. 1), as well as assessing invertebrate abundance and water quality (e.g. 'Riverfly Monitoring Intiative'; see appx. 1). There may be potential for tapping into this, seeing that anglers regularly visit fishing spots and are often well informed about the species they encounter. Due to the licensing process, anglers are trained to identify common fish taxa that are of local interest and thus would be able to identify non-native species more quickly than laypeople. Furthermore, they often keep extensive and detailed records, allowing us to also access historical data. While reports of anglers landing tilapia and even piranhas in the Gillbach-Erft river system have made headlines before, they are, however, unlikely to notice smaller cichlids (e.g. *Amatitlania nigrofasciata, Hemichromis bimaculatus*) or small livebearers such as guppies, mollies and swordtails. National citizen science project databases (e.g. 'Portal Bee', see appx. 1) can also be useful in widening the audience, allowing motivated people seeking a worthy cause to get involved. Further, collaborations with already existing programs can help to successfully combine engagement and data gathering to answer a question of shared interest (see 'Check, Clean, Dry'). One particularly interesting candidate would be the 'Ventus' project (see appx. 1) that gathers information on power plants worldwide. They primarily map locations, but also request other information concerning carbon dioxide emission via simple form filling. Adding a few questions about the surrounding water bodies, their flora and fauna as well as their temperature regime could provide valuable insight for our mission. But even with abundant data, new issues such as data verification, storage and security arise. For example, an internet source had reported a feral guppy population in the thermal springs of Kaiserstuhl near Freiburg (tab. 1), yet we were unable to verify this information. One possible strategy is applied by the North American Breeding Bird Survey, which only codes a species "absent" when data on other parameters or non-focal species has been submitted for this site. In our case, the status of this population remains unknown, but many other TIFs could be eliminated if parameters such as the water temperature or occurrence of native species were recorded instead.

(iv) How feasible is such an effort in this particular case? It is noteworthy, that citizen science is not free. To make a project successful, it requires investment in recruiting, motivating and retaining volunteers, as well as managing and analysing the data that are produced. Germany's goal is to switch off all of its nuclear reactors by 2022 (Federal Gazette 2011). In its mission to significantly reduce greenhouse gas emissions, the German government aims to generate 80% of its electricity from renewables by 2050 (BMWi 2016). Further, many stakeholders call for stricter regulations on thermal pollution in light of climate change and recent ecological assessments (BUND 2009). Current proposals would force many power plants to return their coolant water at a temperature equal to the point of collection. With the future of German TIFs unknown, a comparison with a similar scenario that occurred after the German reunification suggests itself. In the years subsequent to 1989, many Eastern German power stations were unable to compete and either went offline or where substituted by newer models that were more efficient and water conserving. Consequently, guppy and swordtail populations that had inhabited outlets of these power plants (e.g. Lübbenau, Trattendorf; tab. 1) all broke down shortly after. The population of Lake Wölfersheim met a similar fate as the power plant Wölfersheim stopped its operations in 1991. In view of previous developments, thermal refuges and their non-native inhabitants are likely to be impacted by the German energy revolution. With anthropogenic TIFs becoming increasingly scarcer (Wikipedia 2017), the basis for the survival of fish species from warmer regions may no longer be a given.

5. Conclusion

With the newest EU legislation concerning the regulation and management of invasive species

(European Union 2014), the obligation has been placed on EU member states to assess key introduction pathways and develop action plans for preventive measures. Yet, among the top challenges faced by this endeavour are insufficient funding and a lack of awareness (Caffrey et al. 2014). Citizen science can be a powerful tool to improve community awareness of biological invasions and support biomonitoring efforts. To be successful, however, each project needs to be carefully tailored to the specific issues and audience it is designed to address. In addition to the array of studies that have employed citizen science successfully, several guidelines and manuals exist that can provide detailed recommendations and assist in putting projects into practice (see Roy et al. 2012; Tweddle et al. 2012; Pocock et al. 2014a, b).

We believe that our study not only highlights some of the strengths and limitations of a citizen science approach, but also gives more insight to an often overlooked refuge for (sub)tropical neobiota. Our data – while sparse – do further support the assumption that these systems are very localized phenomena (Klotz et al. 2013; Jourdan et al. 2014; Lukas et. al. 2017). Historical records of feral guppies provided us with new examples of population collapses after thermal pollution ceased (tab. 1). In light of Germany's energy revolution and stricter regulations on thermal pollution, this seems to be a likely future scenario for the feral guppy population of the Gillbach. In place of thermal pollution, however, climate change might become the main driver of species' range shifts and adaptive responses. Thus, we call for continuous monitoring to allow for a timely reaction if new invaders or detrimental impacts to the native flora and fauna are detected. Further, we want to encourage more research to take advantage of these systems, which provide a unique opportunity to study the impacts of climate change and species invasion on a small geographical scale. Lastly, we hope our efforts could contribute in raising awareness for the ongoing threat of pet releases and its implication for the endemic flora and fauna.

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Appendix 1: Table of the aforementioned citizen science projects.
Anhang 1: Auflistung der genannten Citizen-Science-Projekte.

Project	Website
Check, Clean, Dry	www.nonnativespecies.org/checkcleandry/
Invasive Tracers	www.InvasiveTracers.com
SeaLifeTracker	www.brc.ac.uk/sealife_tracker/
AquaInvaders	www.brc.ac.uk/aquainvaders/
The Lost Ladybug Project	www.lostladybug.org
Besatzfisch	www.besatz-fisch.de
Digitaler Fischartenatlas	www.fischfauna-online.de
Riverfly Monitoring Intiative	www.riverflies.org/rp-riverfly-monitoring-initiative
Portal Beee	www.portal-beee.de
Ventus	https://ventus.project.asu.edu

Appendix 2: List of public video observations of feral populations of (sub)tropical fish in Germany. All videos were accessed on 31-08-2017.
Anhang 2: Liste mit öffentlichen Videoaufnahmen von wilden, (sub)tropischen Fischpopulationen in Deutschland. Alle Quellen wurden am 31.08.2017 eingesehen.

Location	Reference
Gillbach, NRW	Scheuern R. (2016, Mar 27) *Amatitlania nigrofasciata* im Gillbach. Retrieved from https://www.youtube. com/watch?v=WG6d5LEnO3Y
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	[Ed's Fishbook Het Aquarium kanaal!] (2017, Apr 23) 009 Gillbach wildvang. Retrieved from https://www.youtube.com/watch?v=1hs6gTQoO9A&t=6s
	Lukas J.A.Y., Jourdan J., Kalinkat G., Emde S., Miesen F.W., Juengling H., Cocchiararo B., Bierbach D. (2017): Gillbach cichlids from 'On the occurrence of three non-native cichlid species including the first record of a feral population of *Pelmatolapia* (*Tilapia*) *mariae* (Boulenger, 1899) in Europe'. figshare. Retrieved from https://doi.org/10.6084/m9.figshare.5114023.v1
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