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Brief Report

The Role of Hydrographic Mapping in the Study of Emerging Aquatic Insects on the Landscape Scale

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Abstract: Emerging aquatic insects constitute one of the main biological flows connecting aquatic and terrestrial ecosystems. In a landscape, there are many sources of emergence, which vary in space and time. Thus, they must be clearly defined when studying the inland dispersal of aquatic insects. In this study, we defined five types of hydrographic networks (including or not including ponds and ditches) on the basis of cartographic data of varying degrees of detail (from OpenStreetMap to field map) in order to explain the abundance of aquatic insects. We sampled Ephemeroptera, Plecoptera, Trichoptera, and Megaloptera (ETPM) with 64 sticky traps homogeneously covering a 75 ha agricultural landscape. The abundance of aquatic insects is logically better explained by the hydrographic networks recorded directly in the field than by the reference network, which is incomplete (OpenStreetMap). The results show that, depending on the sampling period, not all water bodies in the landscape are necessarily sources of emergence. To our knowledge, the issue of defining the sources of emerging aquatic insects has never been raised. Based on a practical example, this short note shows that, by refining the hydrographic network to better match the sources of emergence, the explanatory power of inland aquatic insect abundance can be greatly improved.

Keywords: ecosystem connectivity; ditches; ponds; tributaries; merolimnic insect

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1. Introduction

Emerging aquatic insects are major components of fluxes from aquatic to terrestrial ecosystems [1–3]. They are acknowledged as aquatic subsidies and are an integral part of terrestrial food webs [4]. In terrestrial environments, aquatic insects constitute a resource flow, mainly as prey for terrestrial predators [5]. A recent review [6] highlights the ecosystem services provided by emerging aquatic insects, such as pollination, the fertilization of soil, and indirect crop pest control. Almost all imagoes are winged and can fly [7], which allow them to disperse in terrestrial environments. Numerous studies on the dispersal of aquatic insects in terrestrial landscapes have shown a decrease in the abundance of aquatic insects with distance from water [8–10], thus defining a "biological stream width" [11].

The emergence and dispersal of aquatic insects have mostly been studied in permanent streams [12,13] or lakes [14]. Emerging dry mass has been estimated to be 1445–7374 $mg \cdot m^{-2} \cdot y^{-1}$ for streams [15] and 150–3700 $mg \cdot m^{-2} \cdot y^{-1}$ for lakes [16]. However, small water bodies such as ponds host many invertebrate species [17] that can emerge in huge numbers [18,19]. These small aquatic environments are therefore a significant source of emergence, which often varies according to the seasons [20,21]. For example, hydrographic networks vary from 117,500 km^2 in January to 275,800 km^2 in June in northern temperate regions [22], especially in headwaters [20,23]. The water surface in temperate regions is particularly increased seasonally by temporary water bodies (ditches, ponds, and stream tributaries) that collect spring runoff and provide non-permanent aquatic habitats for many aquatic insects [24,25]. Moreover, even in a permanent aquatic environment, aquatic insect emergence is often pulsed [26,27]. In temperate regions, these emergences occur mostly in early spring, providing resources for terrestrial predators, while terrestrial prey have not yet appeared [28]. However, the temporal dynamics are not the same for different species [29]. For example, stoneflies tend to emerge in early spring while caddisflies appear in late spring to early summer [15].

Within a landscape, the sources of emergence of aquatic insects fluctuate spatially and temporally [15,30]. In this short paper, we aim to highlight the importance of accurately defining the sources of emergence when studying the abundance of aquatic insects in terrestrial landscapes. We analyzed the relationship between the distribution of winged insects—Ephemeroptera, Plecoptera, Trichoptera, and Megaloptera (EPTM)—and the distance to the closest water bodies in an agricultural area of 75 ha. Three successive sampling sessions in 2021 (from 1 April to 3 June) were set up to consider the effects of the dynamic of insect emergence and drought-related changes in the hydrological network. We compared the goodness of fit of negative binomial regressions between EPTM abundance and preexisting (and static) hydrographic mapping (i.e., the OpenStreetMap source) and four field hydrographic networks, including or not including ponds and ditches and their evolution over time (i.e., session). Insect abundance is highest near their emerging sources [11]. We therefore hypothesized that the hydrographic network that best explains aquatic insect abundance (i.e., with the highest pseudo R^2) is the one that best represents the emergence sources among the studied networks.

2. Materials and Methods

The study site was located in north-eastern Brittany (France) and is part of the European long-term ecosystem research (eLTER) site known as "Zone Atelier Armorique". The 75 ha study area consisted of a patchy landscape made up of forests, pastures, cropland, and farming zones. The area is crossed by a 33.2 km long first-order stream [31], named the "Guyoult", and includes two permanent ponds. In the study area, we defined the following five hydrographic networks. The first network consisted of the OpenStreetMap (OSM) hydrographic map (Figure 1a), including the drainage of the Guyoult stream and two permanent ponds (network 1). The second network (Figure 1b) corresponded to the completed drainage of the Guyoult stream, obtained by field mapping (network 2). It included the drainage of the Guyoult stream with its intermittent and permanent tributaries (unmapped by OSM), and all the full-water ponds during the sampling period (1 April–3 June). Then, we mapped the full hydrographic networks in the field, including all water bodies (i.e., the main stream, the tributaries, the ditches, and the full-water ponds at the time of the survey) at three successive dates in 2021 (12 April, 5 May, and 27 May, named networks 3, 4, and 5, respectively, as shown in Figure 1c–e). We categorized the water lines by size to estimate the water surface in the landscape. We distinguished the main stream (around 150 cm in width), the tributaries (50–100 cm in width), and the ditches (≤50 cm in width). In order to measure the influence of ponds on the abundance of aquatic insects, all five networks were analyzed with or without ponds.

Insect abundance was obtained using 64 sticky traps [10]. Sticky traps consist of a transparent plastic cover (42 × 29.7 cm, 2 mm-thick), sprayed with non-drying glue (Tanglefoot® and Tangle-Trap® Sticky Coatings). The plastic cover sprayed with glue was fixed cylindrically around a stake at 1 m height to catch insects coming for all possible directions [4]. Three sampling sessions were carried out: session 1 from 1 April to 15 April, session 2 from 26 April to 10 May, and session 3 from 20 May to 3 June 2021. A mapping survey was carried out during each session (networks 3, 4, and 5, respectively). For each session, the sticky traps remained at the same point, and only the plastic covers were replaced. The sticky traps were spaced out by at least 50 m to homogeneously cover the entire study area (Figure 1a,b). In the laboratory, EPTM were extracted from the glue using D-limonene terpene and identified at the order level. For each sticky trap and hydrographic network, the distance to the nearest water body was measured using QGIS v.3.22 software (NNJoin Plugin [32]).

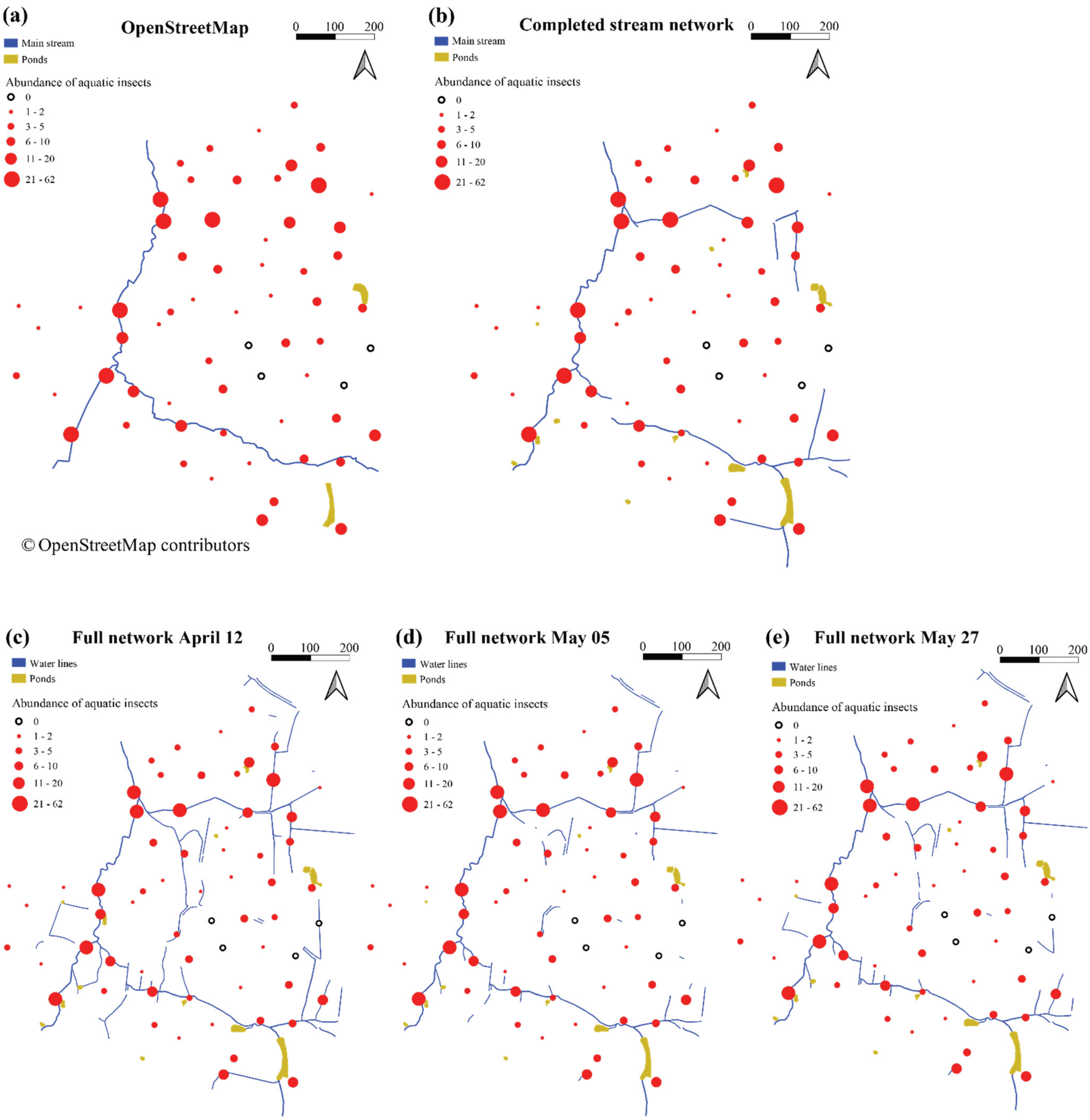

Figure 1. Hydrographic networks. (**a**) Based on OpenStreetMap, including two permanent ponds, with an abundance of aquatic insects. (**b**) The completed drainage of the stream, including the stream tributaries and the full-water ponds from 1 April to 3 June, with an abundance of aquatic insects. Hydrographic networks, including all the water bodies (stream, tributaries, ditches, and small ponds), during the survey period. (**c**) 12 April 2021, (**d**) 5 May 2021, (**e**) 27 May 2021.

Then, for each session, we determined the hydrographic network that best explained the abundance of aquatic insects. Using negative binomial regressions (the "MASS" package [33]) with distance to the nearest water bodies as an explanatory variable and insect abundance as a response variable, we computed the goodness of fit (pseudo R^2, [34]) by orders for each hydrographic network. The significance of each explanatory variable was tested using Anova (the "car" package [35]).

All statistical analyses were performed using the total abundance of EPTM, with R software v. 4.1.1 [36].

3. Results and Discussion

3.1. OpenStreetMap (OSM) Network vs. Field Hydropgrahic Network

The water surface area of the four hydrographic networks studied in the field was up to twice as large as that of the OSM network, ponds included or not (Table 1). Small temporary water bodies such as ditches were understandably not mapped by OSM. However, compared to the field networks, OSM mapping missed 35 to 52% of the potential sources of emerging aquatic insects because it overlooked the intermittent sections of the stream and its tributaries, as well as some small permanent ponds. In this study, the same insect abundance dataset was compared to different hydrographic networks. Therefore, we did not underestimate the quantity of aquatic insects when we refined the hydrographic networks; instead, we just misinterpreted their origin. Aquatic insects can emerge from numerous aquatic habitats in the landscape (e.g., rivers, ditches, and ponds). Thus, their dispersal across terrestrial environments might be overestimated when considering a limited source of emergence (e.g., one type of aquatic habitat, such as a stream) and their abundances misinterpreted.

Table 1. Pseudo R^2 of negative binomial regressions between the distances to the nearest water body of each hydrographic network and the aquatic insect abundance. Numbers in bold represent pseudo R^2 between the aquatic insect abundance of a session and the mapping survey carried out during this session. Each hydrographic network declines with ponds ("P") and without ponds ("NP"). Hydrographic network 1 is the OpenStreetMap stream; network 2 is the completed stream; and networks 3, 4, and 5 are the full networks surveyed on 12 April, 5 May, and 27 May, respectively. Note for *p* values: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

Hydrographic Networks	Water Surface (Ha)		Session 1		Session 2		Session 3	
	P	NP	P	NP	P	NP	P	NP
1	0.52	0.28	0.17 **	0.09 *	0.01	0.01	0.12 **	0.06 *
2	0.85	0.38	0.29 ***	0.31 ***	0.17 **	0.14 **	0.34 ***	0.4 ***
3	1.04	0.53	**0.33 *****	**0.31 *****	0.17 ***	0.14 **	0.31 ***	0.33 ***
4	0.90	0.43			**0.21 *****	**0.2 *****	0.25 ***	0.28 ***
5	0.93	0.46					**0.32 *****	**0.35 *****

Aquatic insect abundance was always better explained by our hydrographic field survey networks (networks 2–5, Table 1) than for OSM mapping (network 1, Table 1). By refining the hydrographic network, without adding factors other than distance from the water bodies, the explanatory power of aquatic insect abundance models was greatly improved. Although OSM mapping is considered to be quite accurate [37], especially in Europe, it may lack completeness in other parts of the world [38]. OSM mapping is often used for large-scale analyses [39], but its use on small scales is limited [40]. Anyone wishing to use OSM on finer scales should carefully check the details of the map before using it. OSM is an open-source project and researchers can update it based on their local study maps to reflect the hydrological networks of interest.

3.2. Differences between the Four Hydrographic Networks

For each session, the water surfaces of the three hydrographic networks (3–5) varied, excluding up to 19% of ponds and including 13% of ponds. For sessions 1 and 2, the abundance of aquatic insects at each sampling session was better explained by the corresponding hydrographic network (pseudo R^2 in bold, Table 1). For session 3, the pseudo R^2

was slightly higher for the completed stream network (including information on the three sessions) (2) than for its corresponding hydrographic network (5). Thus, depending on the time of year, not all water bodies in the landscape are necessarily a source of emergence.

The question of emerging sources has been raised in previous studies on aquatic insect dispersal. To limit the potential influence of temporary ponds and ditches, the distances from streams can be restricted (e.g., to 50 m [10]). Another way of overcoming this issue is to remove aquatic taxa whose larvae cannot live in the aquatic environment under study [41]. Some authors estimated that the majority of sampled aquatic insects came from the nearby stream because the distances to other emerging sources were too high [42] or because the other emerging sources had dried out [43]. While nearly all studies focused on one particular aquatic environment (e.g., a stream, a lake, or a pond), in this study we considered all aquatic elements in the landscape, permanent or temporary, including ponds, tributaries, and ditches. We highlighted their importance in terms of water surface and explanatory power in simple models. Other hydrographic data sources appeared limited (e.g., OSM) or included water sources, from which EPTM do not emerge (e.g., full hydrographic networks 3, 4, and 5, in which all intermittent aquatic environments are considered).

3.3. Ponds

The presence of ponds doubled the water surface without the hydrographic network (Table 1). Within each session, the pseudo R^2 was about the same between the hydrographic networks (ponds included or excluded). The lack of differences between the hydrographic networks (ponds included or excluded) can be explained by the low number of EPTM in the pond ecosystems, which were mainly colonized by Coleoptera, Diptera, Heteroptera, and Odonata [17]. Moreover, in our study, most of the ponds were close to other water bodies. Therefore, the distances from the nearest water bodies of hydrographic networks with ponds and hydrographic networks without ponds were close.

3.4. Other Variables to Delineate Sources of Emerging Aquatic Insects

Distance to water is the main factor which explains the abundances of emerging aquatic insects [11]. We showed that we can greatly improve the explanatory power of models by more precisely defining the sources of emergence. In addition to the abundance of aquatic insects, other variables could help us to spatially and temporally define their sources of emergence. Wind direction can indicate the origin of aquatic insects, especially for small species that can be easily blown away by the wind [44]. Variables triggering the emergence of aquatic insects, such as the light period, weather conditions, and air temperature, could provide information on the temporal effect [45], although these variables vary between species [30], substrate type, and habitat [46].

4. Conclusions

Our results highlight that hydrographic networks must be carefully considered and mapped when studying aquatic insect abundances across terrestrial environments. The use of data sources such as OpenStreetMap can bias the results on emerging aquatic insects. Water bodies are not all sources of emerging insects at a given period, and a classical hydrographic network such as OSM overlooks important water bodies for aquatic insect emergence. Therefore, we recommend using appropriate hydrographic networks according to the ecology of the taxa to be studied in order to consider the sources of emergence of insects as precisely as possible. This study focuses on EPTM, i.e., the most commonly studied aquatic insects in the literature. Further studies using the same approach should be used for other taxa such as Diptera, a potentially important source of subsidies for adjacent terrestrial landscapes.

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