



The impact of channelization on macroinvertebrate bioindicators in small order Illinois streams: insights from long-term citizen science research

Charlie Blake¹ · Allison K. Rhanor¹

Received: 13 September 2019 / Accepted: 12 February 2020 / Published online: 4 March 2020
© Springer Nature Switzerland AG 2020

Abstract

Channelization can have far-reaching and long-term impacts on stream ecology. In this study, we demonstrate that channelization is associated with lower stream quality as measured by macroinvertebrate bioindicators when compared to unchannelized streams. Citizen scientists collected the data for this study between 1995 and 2014, performing 3021 sampling events during the months of May and June across 567 Illinois streams. We found significantly lower taxa richness, EPT taxa richness, and macroinvertebrate biotic index values in channelized sites. Our findings also show prevalent siltation in channelized sites that is likely negatively affecting macroinvertebrates, along with a possible lower availability of quality habitat. We also measured stream velocity and found that average velocity did not differ between our channelized and unchannelized sites. Our findings suggest stream velocity was not a driving factor in determining the differences in macroinvertebrate assemblages, although we cannot comment on the possible change in velocity from pre to post channelization at each site. This study allows for a large dataset that covers diverse streams across the entire state of Illinois. Our work provides example and encouragement for other researchers to take advantage of the power of citizen science, and the existing large datasets available from these projects.

Keywords Bioindicators · Citizen science · Channelization · Erosion · Water quality monitoring

Introduction

People have a long history of modifying waterways for human benefit. In the Midwestern United States, alteration of stream channels has been widespread since European colonization. Growing agricultural interests, and later urbanization, created a need for flooding and erosion control, leading to widespread alteration of stream channels across the region (Urban 2005). Channelization is a prevalent management practice used to control flooding, protect agricultural lands from soil erosion, improve navigability, and eliminate wetlands for urban and agricultural development (Hupp 1992). This is accomplished through a suite of engineering techniques that may include intentional or subsequent deepening and widening of the channel, removal of riparian vegetation,

and sometimes the replacement or supplementation of natural banks with constructed materials (Brooker 1985; Urban 2005). The impacts of channelization can continue to affect geomorphological and ecological processes for decades, particularly if the alteration spurs an increase in stream velocity and sediment transport that can set off fluvial positive feedback loops (Urban and Rhoads 2003).

In addition to the extensive changes in the geomorphology of rivers that can result from the direct and indirect impacts of channelization, changes to the physical template of freshwater habitats can have profound effects on biota and ecosystem function (Faukner 2004; Poff et al. 2007). Channelization reduces habitat heterogeneity which can result in the loss of sensitive fish species and an overall reduction in fish diversity (Lau et al. 2006). In addition, macroinvertebrate communities are strongly connected to the ecology of surrounding terrestrial areas including changes to stream banks structure, canopy cover, and land use (Harding and Winterbourn 1995; Hrodey et al. 2009). Previous research suggests that benthic macroinvertebrate richness and relative abundance can be affected by several inter-related stream morphology factors (Horsak et al. 2009; Hrodey et al. 2009;

✉ Charlie Blake
charliekrblake@gmail.com

¹ National Great Rivers Research and Education Center,
Lewis and Clark Community College, 1 Confluence Way,
East Alton, IL, USA

Kennedy and Turner 2011). For example, certain species that feed on suspended particles depend on flowing water for food delivery and cannot survive in low flow environments in which their food source will settle out of the water column (Wallace and Merritt 1980). Conversely, other species cannot survive environments in which the suspended particle load is too high (Dodds and Whiles 2010).

Although it is known that flow affects macroinvertebrate species in many direct and indirect ways (Hart and Finelli 1999), many studies on the relationship between stream morphology and stream biota have focused on a single river or have had limited replication over a particular geographic area or time period. For example, Lau et al. (2006) looked at the impacts of channelization on fish in Indiana, but high replication is not always feasible and this study allowed for only 20 channelized sites spread over just a small portion of the state, with sampling occurring during a single summer. Some studies have shown channelization to have negative impacts on macroinvertebrate assemblages (Schmal and Sanders 1978; Kairo et al. 2017), but are also limited in either geographic or temporal scope. The relationship between macroinvertebrates and channelization has also been explored when a management project presents the chance to sample before and after a stream undergoes restoration (Laasonen et al. 1998; Lepori et al. 2005; Muotka et al. 2002). While before-and-after studies provide support for the idea that restoration of previously disturbed streams can have marked positive effects on macroinvertebrates, constraints on the scale of these types of field experiments, such as location, timing, and number of replicates, has understandably limited the scope of these studies, and long-term monitoring of restoration success is not common.

Use of macroinvertebrate communities for assessing the biological integrity of freshwater habitats is a well-established approach for assessing overall ecosystem integrity (Barbour et al. 1999; Wallace et al. 1996; Bo et al. 2017; Buss et al. 2018). The variability in life cycle lengths and sensitivities to environmental changes represented in macroinvertebrate assemblages makes them ideal candidates for biological assessments (Barbour et al. 1999; Wallace et al. 1996). By using biotic indicators, multiple stressors affecting the animal over its lifetime are reflected in each sample taken, whereas most standard measurements of the physical habitat and water chemistry provide just a “snap-shot” of environmental quality at the time of sampling (Barbour et al. 1999; Carter et al. 2006). These macroinvertebrate-based biological assessments often include some form of an index using the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT), as these species are generally sensitive to pollution (Barbour et al. 1999; Doretto et al. 2018; Mebane 2001).

The present study utilizes a large dataset that provides a rare opportunity to examine the relationship between

macroinvertebrate bioindicators and channelization with both plentiful temporal and geographic replication across an entire state. These data were collected by our trained citizen scientists as a part of the Illinois RiverWatch Network and allow us to demonstrate the effects of channelization on stream condition through long-term monitoring. In addition, we examined how siltation coverage relates to channelization, and how the type of available habitats varied between channelized and unchannelized streams. The goal of this study was to not only provide an analysis of channelization effects, but also to demonstrate the utility and availability of large datasets through citizen science and how these datasets can be used to augment established experimental designs to help answer unique or challenging scientific questions.

Methods

The Illinois RiverWatch Network

The Illinois RiverWatch Network originated in 1995 along with a proliferation of volunteer monitoring programs in many states across the U.S. (Baker 2002; Firehock and West 1995). Originally developed and administered by the Illinois Department of Natural Resources, the National Great Rivers Research and Education Center took over coordination of the program in 2006. Since its inception, the Illinois RiverWatch Network has collected data on habitat and biotic variables in small order streams by employing trained citizen scientists, resulting in a dataset containing over two decades of data. Data for this study were collected between the years of 1995 and 2014 and includes 3,021 sampling events during the months of May and June across 567 Illinois streams with 2515 samples from unchannelized sites and 506 samples from channelized sites. The statistical power afforded by a dataset of this size allows for the examination of broad ecological patterns that can sometimes be lost amongst the noise of many interacting variables when dealing with more typical, smaller datasets that may have geographic and temporal constraints. While some researchers may question the accuracy of data collected by citizen scientists, there is now ample precedent showing that citizen science can yield quality data that can allow for studies that would previously have been impossible due to their impractical scale (Crall et al. 2011; Ellwood et al. 2018; Mayor et al. 2017; McShea et al. 2016; Datry et al. 2016; Edwards 2016). There is also previous research that specifically verifies the macroinvertebrate identification of citizen scientists (Edwards 2016), and we are confident our rigorous quality checks further add to the credibility of this method.

Training citizen scientists

To become a citizen scientist, each volunteer paid a registration fee to participate in a full day of training that included both classroom instruction in macroinvertebrate identification and outdoor instruction in stream monitoring methods. In addition, all citizen scientists received a printed manual (nearly 150 pages) of detailed instructions on collection and identification methods (Illinois RiverWatch Stream Monitoring Manual 2015). Participants also have access to the complete manual and online biotic index calculator through our website. After collection, we offered open laboratory sessions for citizen scientists to process their samples, where the RiverWatch coordinator provided access to microscopes and assistance in macroinvertebrate identification.

Site selection

We selected sites for the RiverWatch program with input from citizen scientists based on their accessibility on foot and their depth during the summer sampling period. Streams needed to reliably have enough water to sample during the sampling period May 1st through June 30th and be wadeable during those months (generally less than 0.61 m in depth). These criteria enabled the sites to be easily sampled by citizen scientists using the same minimal equipment for each site. Because citizen scientists come and go from the program, not every site is monitored every year and some sites may have been monitored by different observers in different years, but all sites were monitored at least once by trained citizen scientists using the same protocol (Fig. 1). Approximately 26% of the sampling sites were only sampled once, but most sites were sampled multiple times (channelized Mean \pm SE = 3.02 ± 0.33 , unchannelized Mean \pm SE = 3.64 ± 0.12 , with the maximum being a single site sampled in 18 different years). In addition to recording the GPS location of each site, citizen scientists drew a detailed site sketch each year to ensure consistency of site location and to provide supplemental data on changing habitat conditions, and took site photos if possible.

Habitat sampling

Each site is 61 m in length, as measured following along the wetted edge of the streambank. Sites were further divided into four 15.25 m segments to assess habitat parameters, which included substrate composition, siltation coverage, and stream velocity, among a multitude of other variables not relevant to the present study. To describe substrate, citizen scientists followed a slightly modified Wentworth grain size classification method so that stream bottom material was categorized as bedrock, boulder (> 305 cm), cobble (76–305 cm), gravel

Number of years sampled

- 0-2
- 3-4
- 5-6
- 7-9
- 10-11
- 12-13
- 14-16
- 17-18

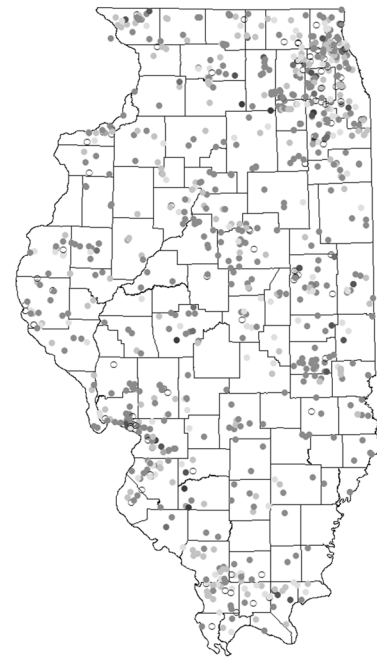


Fig. 1 Stream monitoring site locations with darker marks representing sites sampled more frequently during the study period, 1995–2014

(2.75–75 cm), sand (0.76–2.74 cm), or silt (<0.75 cm) (Wentworth 1922). Citizen scientists then recorded what percentage of the substrate is made up of each material based on visual estimation. The estimates were then averaged for each 15.25 m section to obtain an overall estimate of substrate composition for the site. In addition, siltation coverage was recorded as a separate measure that accounts for the amount of fine particulates blanketing the stream bottom, which is similar to measures of embeddedness. Siltation coverage describes the portion of the bottom substrate that is covered in a layer of silt, though the substrate itself may be composed of other materials (such as cobble), while percent silt substrate describes the proportion of substrate that is composed of pure silt. Therefore, siltation coverage could be substantially higher than silt substrate for the same stretch of stream.

Stream velocity was calculated using the float method. Although this method lacks the precision of digital meter methods, the float method is relatively reliable in the types of small streams included in this study (Dobriyal et al. 2017; Hamilton and Moore 2012; Harrelson et al. 1994). Citizen scientists marked off a 3.05 m run within the site that was free from debris or other obstacles. The run was then divided into three transects equally spaced across the width of the stream and marked these sections with flags. To take the velocity measurement, citizen scientists used a neutrally

buoyant perforated golf ball which they allowed to float the length of the flags. This procedure was repeated for each of the three transects and recorded the amount of time in seconds it took the float to pass 3.05 m downstream. Velocity was calculated in meters/second and averaged the three measurements to obtain the stream velocity for the site.

Biological sampling

Macroinvertebrates were collected from two habitat types at every site. Citizen scientists selected which habitats to sample following an established hierarchy based on those habitats that generally have the most diverse macroinvertebrate communities, with riffles being the most diverse, followed by leaf packs, woody snags or logs, undercut banks, and finally sediments (Costa and Melo 2008; Heino et al. 2004). Thus, if there were riffles present, these were always sampled, as well as the next most diverse habitat present at the site. This procedure is used so that each sampling event should detect the most diverse and most sensitive species present at a given site at that sampling time. This protocol is also well-suited for our study that focuses on long term monitoring, as the microhabitats available at a particular site could shift over the course of several years. Citizen scientists conducted sampling in pairs so that one person could hold the net downstream while the other disturbed the habitat to release organisms into the net. Detailed methods for sampling each habitat type are described in the Illinois RiverWatch Stream Monitoring Manual (2015). While microhabitats were not counted directly, we were able to glean information on habitat availability based on which habitats were sampled for macroinvertebrates, as citizen scientists always collected from the two most high-quality habitats available and recorded which habitat types were sampled on their data sheets. We preserved macroinvertebrates in isopropyl alcohol for subsequent identification.

Following field collections, samples were marked as accepted into the database only if they contained at least 25 individual organisms, but all submitted samples were still recorded. A minimum count per sample is not uncommon for citizen science stream monitoring programs (Edwards 2016), and acts as a quality control measure to ensure adequate sampling efforts that are similar across all sites. This minimum count led to only 377 samples being excluded from the 3430 total samples that were actually collected during this time period of this study. If the sample contained more than 100 organisms, it was sub-sampled by placing the original sample in a grid tray and collecting organisms from enough randomly selected grid squares to reach 100 individuals or slightly more if this target was reached while in the middle of a grid square, as per the EPA's Rapid Bioassessment Protocol (RBP) (Barbour et al. 1999). In addition to being adapted from the EPA's RBP, the 100 individual

target was chosen as a suitably high number that still allowed the program to be accessible to trained citizen scientists. Not only does sub-sampling make dealing with a large number of individuals feasible for a citizen scientist, but it is considered to be an acceptable way to counter the prohibitive costs and amount of time associated with identification of large samples, especially when the objective is to determine differences between sites rather than determining variance at each site (Merritt et al. 2008). Further, previous research has found that macroinvertebrate sub-sampling by citizen scientists within the field produces sound data when compared to sub-sampling done by experts in laboratory settings (Edwards 2016).

Once all macroinvertebrates in the sample were identified, or subsample when applicable, the counts were recorded based on the groupings detailed in the Illinois Riverwatch Stream Monitoring Manual (2015) that are outlined in Table 1. These were then used to calculate the Macroinvertebrate Biotic Index (MBI). MBI is a metric developed by the Illinois EPA, modified from methods of the US EPA and the Hilsenhoff Biotic Index HBI, which uses the known tolerance level of poor environmental conditions of different taxa (Hilsenhoff 1987, 1998; USEPA 1990). Although some of our categorizations include organisms of multiple taxa, the index was designed with enough specificity to distinguish between groups with varying levels of sensitivity to water quality (Table 1). Streams were categorized along a spectrum of poor to excellent based on their numeric values for taxa richness, EPT taxa richness and MBI (Table 2).

Quality assurance

After the sampling period of May–June, citizen scientists had until September 1st to send their samples to the RiverWatch Coordinator. Between June and September of each year, the RiverWatch Coordinator hosted open-laboratory sessions throughout the state, giving citizen scientists access to microscopes and expert assistance for the macroinvertebrate identification portion of the data sheets. Only data sheets submitted with complete information and accompanying preserved specimens are accepted into the database. Additionally, a minimum of 25% of samples are randomly selected and quality checked for accuracy by an expert every year. Since 2005, we have contracted with staff at the Illinois Natural History Survey (INHS) to complete our quality checks. When quality assurance officers checked citizen science data, samples were considered within an acceptable range of accuracy if the citizen scientist counts had less than 20% absolute difference from expert counts for richness and EPT index, and 10% difference for MBI. For the 10 year period between 2005 and 2014, the mean percent of samples that fell within the acceptable accuracy range was 74.1 ± 3.9 for Taxa

Table 1 Macroinvertebrate taxa groupings used in the Illinois RiverWatch protocol and their corresponding tolerance index values used to calculate the macroinvertebrate biotic index (MBI)

Organism group	Tolerance index value	Unchan-nelized Mean \pm SE	Channelized Mean \pm SE
Flatworm (Order Turbellaria)	6	2.13 \pm 0.16	3.88 \pm 0.60
Aquatic Worm (Order Oligochaeta)	10	2.36 \pm 0.22	4.42 \pm 0.55
Leech (Order Hirudinea)	8	0.75 \pm 0.05	1.98 \pm 0.17
Sowbug (Family Asellidae)	6	15.52 \pm 0.73	21.06 \pm 2.27
Scud (Order Amphipoda)	4	10.89 \pm 0.76	9.42 \pm 0.98
Dragonfly (Suborder Anisoptera)	4.5	0.39 \pm 0.02	0.46 \pm 0.08
Broadwinged Damselfly (Family Calopterygidae)	3.5	0.47 \pm 0.03	0.48 \pm 0.08
Narrowwinged Damselfly (Families Coenagrionidae, Lestidae)	5.5	1.28 \pm 0.10	3.03 \pm 0.37
Dobsonfly (Family Corydalidae)	5.5	0.14 \pm 0.01	0.05 \pm 0.01
Alderfly (Family Sialidae)	7.5	0.04 \pm 0.01	0.02 \pm 0.01
Torpedo Mayfly (Families Isonychiidae, Oligoneuriidae)	3	1.05 \pm 0.11	0.31 \pm 0.11
Swimming Mayfly (Families Acanthametropodidae, Ameletidae, Baetidae, Metretopodi- dae, Siphonuridae)	4	5.42 \pm 0.28	3.3 \pm 0.34
Clinging Mayfly (Family Heptageniidae)	3.5	3.20 \pm 0.14	1.77 \pm 0.28
Crawling Mayfly (Families Tricorythidae, Caenidae)	5.5	2.21 \pm 0.15	3.50 \pm 0.58
Burrowing Mayfly (Families Ephemeridae, Palingeniidae, Polymitarcyidae, Potamanthi- dae)	5	0.35 \pm 0.06	0.19 \pm 0.08
Armored Mayfly (Family Baetiscidae)	3	0.02 \pm 0.008	0.006 \pm 0.004
Other Mayfly (Families Ephemerellidae, Leptophlebiidae)	3	0.32 \pm 0.04	2.20 \pm 0.14
Stonefly (Order Plecoptera)	1.5	0.14 \pm 0.04	1.47 \pm 0.31
Hydropsychid Caddisfly (Family Hydropsychidae)	5.5	15.89 \pm 0.60	9.38 \pm 0.81
Snail Case Caddisfly (Family Glossosomatidae)	3	0.40 \pm 0.06	0.73 \pm 0.25
Saddle Case Caddisfly (Family Helicopsychidae)	0	0.17 \pm 0.03	0.20 \pm 0.07
Other Caddisfly (Families Brachycentridae, Hydroptilidae, Lepidostomatidae, Leptoceri- dae, Limnephilidae, Molannidae, Philopotamidae, Phryganeidae, Polycentropodidae, Psychomyiidae, Rhyacophilida, Sericostomatidae)	3.5	1.59 \pm 0.18	1.11 \pm 0.23
Riffle Beetle (Families Elmidae, Dryopidae)	5	6.68 \pm 0.23	4.33 \pm 0.49
Whirligig Beetle (Family Gyrimidae)	4	0.29 \pm 0.05	0.08 \pm 0.02
Water Penny Beetle (Family Psephenidae)	4	0.61 \pm 0.07	1.15 \pm 0.27
Crane Fly (Family Tipulidae)	4	0.45 \pm 0.3	0.25 \pm 0.04
Biting Midge (Family Ceratopogonidae)	5	0.55 \pm 0.09	0.46 \pm 0.11
Bloodworm Midge (Family Chironomidae, Genus <i>Chironomus</i>)	11	2.56 \pm 0.21	3.93 \pm 0.80
Midge (Family Chironomidae)	6	16.85 \pm 0.54	16.48 \pm 1.37
Black Fly (Family Simuliidae)	6	9.17 \pm 0.52	6.82 \pm 0.77
Snipe Fly (Family Athericidae)	4	0.04 \pm 0.007	0.02 \pm 0.005
Other Fly (Families Culicidae, Tabanidae, Stratiomyidae, Empididae, Syrphidae, Ephydri- dae, Muscidae)	10	0.42 \pm 0.03	0.37 \pm 0.06
Left-Handed Snail (Family Physidae)	9	2.92 \pm 0.19	4.79 \pm 0.60
Right-Handed Snail (Family Lymnaeidae)	7	0.73 \pm 0.07	1.26 \pm 0.22
Planorbid Snail (Family Planorbidae)	6.5	0.17 \pm 0.02	0.42 \pm 0.07
Limpet (Family Ancyliidae)	7	0.12 \pm 0.02	0.06 \pm 0.02
Operculate Snail (Families Bithyniidae, Hydrobiidae, Pleuroceridae, Viviparidae)	6	1.67 \pm 0.25	3.03 \pm 1.07

The righthand columns show results from our stream monitoring efforts with the mean values of these organisms collected in channelized and unchannelized sites

Richness, 66.3 ± 3.9 for EPT Taxa Richness, and 83.7 ± 4.9 for MBI (Mean \pm SE). The RiverWatch coordinator corrected any samples revealed to have errors and contacted

volunteers with significant inconsistencies in their identifications or counts to supplement their training and improve their future accuracy.

Table 2 Stream quality rating categories used in the Illinois River-Watch protocol

	Taxa richness	EPT taxa richness	MBI
Excellent	≥ 14	≥ 5	≤ 4.35
Good	12–13	4	≥ 4.36 to ≤ 5.00
Fair	9–11	3	≥ 5.01 to ≤ 5.70
Poor	7–8	2	≥ 5.71 to ≤ 6.25
Very poor	≤ 6	0–1	≥ 6.26

Additionally, the RiverWatch coordinator examined samples submitted by all first year citizen scientists whose samples were not included in the randomly selected samples sent to INHS to ensure accurate identification by new participants. After their first year, citizen scientists subsequently had to pass a refresher quiz every two years to demonstrate their continued capabilities in macroinvertebrate collection methods and identification. Consequently, the only samples not verified by either the RiverWatch coordinator or the INHS Quality Assurance Officer are those samples submitted by citizen scientists that have passed their first year check by the RiverWatch coordinator and have passed their bi-annual refresher quizzes with a grade of 80% or better. Falling below this threshold on the refresher quiz, or falling below the acceptable thresholds for quality assurance by INHS if their sample is among those randomly selected, will result in future samples being again verified by the RiverWatch coordinator until the participant can produce identifications above these thresholds. Following these protocols resulted in 1075 of the 3021 samples included in this study being check by professional RiverWatch staff or external experts, with the remainder being only samples submitted by experienced and tested citizen scientists.

Table 3 Difference between unchannelized and channelized streams in several biological measures of stream health based on macroinvertebrate bioindicators, and several measures of physical habitat characteristics

	Unchannelized (N = 2515)	Channelized (N = 506)	Z	P
	Mean ± SE	Mean ± SE		
Taxa richness	9.01 ± 0.07	8.73 ± 0.14	-2.20	0.026
EPT richness	2.73 ± 0.04	2.06 ± 0.08	-7.85	< 0.001
MBI	5.65 ± 0.02	6.06 ± 0.05	7.93	< 0.001
Silt substrate	2.97 ± 0.03	3.47 ± 0.07	6.25	< 0.001
Siltation coverage	3.54 ± 0.03	3.78 ± 0.07	2.79	0.005
Stream velocity	0.298 ± 0.01	0.283 ± 0.01	0.273	0.785

A lower macroinvertebrate biotic index (MBI) signifies better water quality. Stream velocity is measured in m/s. Statistics show the results of Wilcoxon sign rank test with significant results in bold

Statistical analyses

Using a goodness of fit test for a fitted normal distribution we determined that our data were not normally distributed, therefore we used Wilcoxon (Mann–Whitney) tests to assess differences in taxa richness, EPT taxa richness, MBI, silt substrate, siltation coverage, and stream velocity between channelized sites and sites with un-altered banks. We also ran logistic regression analysis to assess the relationship of each of these factors to the probability that the stream was channelized. For all our analyses we chose to treat each sampling event as independent since a full year or more had passed between each sample even if they were taken at the same stream site, and the number of samples per site did not vary greatly between groups (channelized Mean ± SE = 3.02 ± 0.33, unchannelized Mean ± SE = 3.64 ± 0.12). We performed statistical analyses in JMP 14.01.

Results

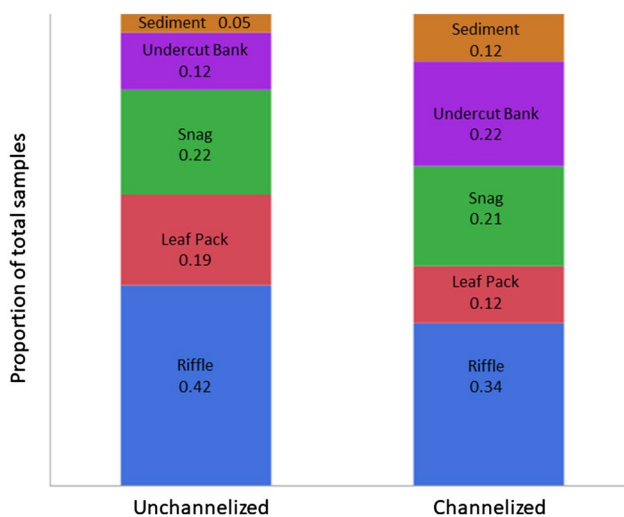
The most numerous taxa collected for both channelized and unchannelized streams was sowbugs (Family Asellidae), which are moderately tolerant of poor conditions (Table 1). There were significant differences in Taxa Richness ($P=0.026$), EPT Richness ($P<0.001$), and MBI ($P<0.001$) between channelized streams and unchannelized streams (Table 3). Using the quality rating classification system developed along with these bio-indices, channelized sites had on average “Poor” quality ratings, while sites with un-altered banks had on average “Fair” quality ratings (Table 2).

The percent of silt substrate was significantly different between channelized and non-channelized sites ($P<0.001$), with channelized sites having substrates composed of more silt (Table 3). Siltation coverage was also significantly higher in channelized sites than in streams with un-altered banks

Table 4 Results from logistic regression analysis showing the relationship of biological and physical stream factors to whether the stream was channelized

	β	SE	X^2	<i>P</i>
Taxa richness	0.087	0.023	13.43	< 0.001
EPT richness	-0.296	0.048	37.10	< 0.0001
MBI	0.149	0.055	7.38	0.006
Silt substrate	0.152	0.044	12.20	< 0.001
Siltation coverage	-0.034	0.039	0.76	0.3844
Stream velocity	0.03061157	0.0715261	0.18	0.6687

Bold values indicate statistical significance

**Fig. 2** The proportion of samples that included each habitat type for channelized and unchannelized stream sites

($P=0.005$) (Table 3). In contrast, there was no significant difference in stream velocity between the two stream types (Table 3). The results of our regression analysis showed that Taxa Richness, EPT Richness, MBI and siltation coverage all had significant relationships to whether the stream was channelized (Table 4).

For both channelized and un-altered sites, the most common habitat sampled was a riffle (Fig. 2). However, there were differences in the habitats available for sampling between channelized and unchannelized sites. Unchannelized sites had more riffles and leaf packs, while channelized sites had fewer of these higher quality habitats available for sampling (Fig. 2).

Discussion

Our findings show differences not only in macroinvertebrate bioindicators between channelized and unchannelized sites, but also physical habitat characteristics that may help

explain the impacts on macroinvertebrates. Flow is considered to be the “master variable” in rivers, as it is the defining characteristic of lotic environments and their associated habitats (Power et al. 1995). Moving water shapes other aspects of the physical template of streams by influencing channel morphology, temperature, and habitat heterogeneity (Power et al. 1995; Dewson et al. 2007). These dynamic physical attributes of streams in turn act to shape biotic communities by applying selective pressures on organisms in instances of extremes (Hart and Finelli 1999; Poff and Allan 1995; Poff et al. 1997; Poff and Ward 1989; Power et al. 1995; Resh et al. 1988; Rempel et al. 2000; Lamouroux et al. 2013). Channelization directly influences this “master variable”, and our study found that overall stream quality as indicated by macroinvertebrate assemblages was higher in streams that had un-altered banks compared to those streams that have been channelized. One likely source for the decreased diversity of macroinvertebrates in channelized streams is habitat loss. Even in streams that were channelized long ago, habitats are often more homogenous than in un-altered streams, with more low-quality habitats like runs of open sediment (Giller 2005; Lepori et al. 2005; Shields et al. 1998). Although we did not directly measure mesohabitat prevalence in this study, our data do show that channelized sites had fewer high-quality habitats available to sample, and we surmise that loss of habitat heterogeneity may have affected habitat availability for macroinvertebrates.

Another factor contributing to poorer habitat quality and thus less diverse macroinvertebrate communities could be the result of siltation. The process of channelization can often increase turbidity and siltation coverage (Ciszewski and Czajka 2015; Graf et al. 2016). This effect is not confined just to the construction process itself, but can continue afterwards due to loss of riparian vegetation and changes in stream geomorphology. Previous research has shown that stream morphology and habitat characteristics are important predictors of macroinvertebrate biotic indices, including land-use, canopy cover, erosion power, percent fine substrates, and degree of channelization (Graf et al. 2016; Hrodey et al. 2009). Increased turbidity and siltation coverage create poor conditions for macroinvertebrates, especially sensitive species (Bryce et al. 2010; Buendia et al. 2013). Our results coincide with these previous studies as we saw a significant difference in prevalence of silt substrate and siltation coverage between channelized and unchannelized sites.

In addition to macroinvertebrate assemblages being a proxy for water quality, a decrease in macroinvertebrate diversity can have real impacts on stream ecosystem functions and foodweb dynamics (Wallace and Webster 1996; Warren et al. 1964; Bona et al. 2016; Doretto et al. 2016). Further, changes in macroinvertebrate quantity and quality can be far-reaching and can negatively affect the surrounding terrestrial habitats. Macroinvertebrates that emerge from the

water as adults (the insect groups) serve to link freshwater and terrestrial ecosystems (Baxter et al. 2005; Gratton and Vander Zanden 2009; Nakano and Murakami 2001). While subsidies to freshwaters from surrounding terrestrial systems are typically driven by gravity and dominated by detritus (e.g., leaf litter inputs from riparian forests), subsidies in the opposite direction usually work against gravity, making emerging insects a key connection (Baxter et al. 2005). Thus, any negative impacts to the macroinvertebrate community we observed in channelized streams could translate to negative consequences for surrounding terrestrial ecosystems as well.

It is important to note that our findings cannot confirm a direct causal relationship of channelization on macroinvertebrate communities. Our analysis was limited by working with an already existing dataset that was not designed with our specific research questions in mind. We cannot rule out that a latent variable such as degree of urbanization could be associated with both channelization and poor stream quality. However, we did not find any evidence that average stream velocity is causing the observed differences in macroinvertebrates between channelized and unchannelized streams. Although previous research shows that channelization often increases stream velocity (Urban and Rhoads 2003), our study design did not actually measure changes in stream velocity following the channelization process. We also did not measure high flow events, but only the velocity at the single time the stream sampling was conducted. Rather, what our data illustrate is that there was no overall difference in average velocity of a site during the sampling period between the channelized and unchannelized streams in this study. It is likely that stream velocity did increase from historic levels in the streams that were channelized, but average stream velocity was not the driving factor in the differences we observed in the macroinvertebrate communities.

In response to research illustrating the potential long-term negative consequences of anthropogenic channelization, several legal measures have increased the regulation of channelization and changed the management strategy of previously modified waterways to favor restoration (Clean Water Act 1972; Water Resources Development Act 1990). However, river management policy remains contentious in areas where flooding of residential areas and/or destruction of farmland are serious concerns (Chen et al. 2016). Our study is unique in that it uses data collected by members of the very communities that are stakeholders in the management of these waterways. Especially when controversial management decisions must be made, buy-in from as many people as possible can ease the implementation of management policy and improve outcomes for the greatest number of people (Barbour et al. 2008).

Citizen science can allow lay people to develop a sense of ownership over scientific evidence that will be used to make

decisions that directly affect them. Participatory scientific studies also increase scientific literacy and the perceived trustworthiness of scientific studies (Storey et al. 2016). Previous research has also shown that people are more likely to be concerned about environmental issues and engage in stewardship behaviors when their identity is connected to their engagement with the environment (Landon et al. 2018). Further, two-way interactions between scientists and the community are much more meaningful than one-directional science outreach efforts (Lee and VanDyke 2015). Citizen science can be particularly powerful for engaging the public with issues that may be controversial and can promote more evidenced-based discussions (Colborn et al. 2011; Wylie et al. 2016; Zilliox and Smith 2018). We hope that the current study encourages other scientists to take advantage of publicly available citizen science data, as there are valuable insights to be discovered, especially from large long-term monitoring datasets.

It is also true that some projects are too large to complete without the efforts of citizen scientists, and part of the strength of this study comes from our large samples sizes. There were numerous differences present among the many streams and sampling events in this study, yet our dataset was large enough to overcome much of that noise and determine that channelization has enough impact on streams to be discernable despite the many variables at play. In fact, we argue that the high variability in some of these unmeasured variables only emphasizes that channelization has a significant impact across many contexts, and illustrates that our findings are applicable beyond a single landscape type within Illinois. Additionally, while we are confident that our sample sizes are large enough to account for occasional misidentification of channelization by our citizen scientists, if misidentifications did occur, it is more likely that a channelized stream was misidentified as being unchannelized rather than the other way around, as some channelization is not obvious. Thus, if anything our results would be underestimating the effects of channelization. Also, the results of the quality assurance tests show that citizen scientist assessments of the macroinvertebrate community and classification of stream health are overall reliable. In fact, the latest data from 2018 sampling showed that 100% of the samples check by INHS were within the 10% margin of error of the expert count for MBI (Detmer et al. 2018). While the data for this study did not include this most recent sampling campaign, it illustrates the quality of the data we received from citizen scientists.

While our findings are not entirely unexpected, this is the first study we know of to illustrate this broad pattern on such a large scale with geographic and temporal replication across an entire state and over several decades. The channelized streams in this study varied in the amount of time since their alteration, but in some cases it would have been many

years since any active channelization activities had been performed. This may indicate that the effects of channelization could persist for a very long time after the alteration if no restoration is enacted. The breadth of this study allows us to conclude that regardless of additional factors that may influence water quality and macroinvertebrate communities, past channelization alone is a significant predictor of stream quality as measured by macroinvertebrate bioindicators. These findings reinforce the importance of considering the long-term impacts of channelization on stream ecology, and suggest that active restoration efforts may be called for even when many years have passed since the channelization event. It is our hope that the comprehensive scale of this study can serve as justification for more detailed studies around the impacts of channelization on macroinvertebrate communities, as well as motivation to employ the work of citizen scientists to expand the possibilities of field studies that would otherwise be restricted in geographic and temporal scope or limited to computer modeling.

Acknowledgements This project would not have been possible without the efforts of thousands of volunteer citizen scientists across Illinois. We thank all previous staff, trainers, and coordinators of Illinois RiverWatch, especially Matthew Young, and the Illinois Department of Natural Resources. Jim Bland provided expertise in developing materials for macroinvertebrate identification. In addition, we thank the Illinois Natural History survey for assistance with quality checks, especially Thomas Detmer.

Compliance with ethical standards

Conflict of interest The authors state that we have no conflicts of interest regarding this work.

References

- Baker D (2002) Creating a report card for riverwatch stream quality. Illinois Department of Natural Resources
- Barbour MT, Gerristen BD, Stribling JB (1999) Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. In: Water OO, editor, 2nd edn. U.S. Environmental Protection Agency, Washington, D.C
- Barbour MT, Poff NL, Norris RH, Allan JD (2008) Perspective: communicating our science to influence public policy. *J N Am Benthol Soc* 27(3):562–569
- Baxter CV, Fausch KD, Saunders WC (2005) Tangled webs: reciprocal flows of invertebrate prey link streams and riparian zones. *Freshw Biol* 50:201–220
- Bo T, Doretto A, Laini A, Bona F, Fenoglio S (2017) Biomonitoring with macroinvertebrate communities in Italy: what happened to our past and what is the future? *J Limnol* 76(S1):21–28
- Bona F, Doretto A, Falasco E, La Morgia V, Piano E, Ajass R, Fenoglio S (2016) Increased sediment loads in alpine streams: an integrated field study. *River Res Appl* 32(6):1316–1326
- Brooker MP (1985) The ecological effects of channelization. *Geogr J* 151:63–69
- Buss DF, Carlisle DM, Chon TS, Culp J, Harding JS, Keizer-Velk HE, Robinson WA, Strachan S, Thirion C, Hughes RM (2018) Stream biomonitoring using macroinvertebrates around the globe: a comparison of large-scale programs. *Environ Monit Assess* 187:4132
- Bryce SA, Lomnický GA, Kaufmann PR (2010) Protecting sediment-sensitive aquatic species in mountain streams through the application of biologically based streambed sediment criteria. *J N Am Benthol Soc* 29:657–672
- Buendia C, Gibbins CN, Vericat D, Batalla RJ, Douglas A (2013) Detecting the structural and functional impacts of fine sediment on stream invertebrates. *Ecol Ind* 25:184–196
- Carter JL, Resh VH, Hanford MJ, Myers MJ (2006) Macroinvertebrates as biotic indicators of environmental quality. Academic, San Diego, pp 805–833
- Chen X, Wang DB, Tian FQ, Sivapalan M (2016) From channelization to restoration: sociohydrologic modeling with changing community preferences in the Kissimmee River Basin, Florida. *Water Resour Res* 52:1227–1244
- Ciszewski D, Czajka A (2015) Human-induced sedimentation patterns of a channelized lowland river. *Earth Surf Proc Land* 40:783–795
- Clean Water Act (1972) 33 U.S.C. §§1251–1387
- Colborn T, Kwiatkowski C, Schultz K, Bachran M (2011) Natural gas operations from a public health perspective. *Hum Ecol Risk Assess* 17:1039–1056
- Costa SS, Melo AS (2008) Beta diversity in stream macroinvertebrate assemblages: among-site and among-microhabitat components. *Hydrobiologia* 598:131–138
- Crall AW, Newman GJ, Stohlgren TJ, Holfelder KA, Graham J, Waller DM (2011) Assessing citizen science data quality: an invasive species case study. *Conserv Lett* 4:433–442
- Datry T, Pella H, Leigh C, Bonada N, Huguéy B (2016) A landscape approach to advance intermittent river ecology. *Freshw Biol* 61(8):1200–1213
- Detmer TM, Olinger D, Parkos JJI (2018) Illinois riverwatch stream monitoring quality assurance report. Illinois Natural History Survey
- Dobryial P, Badola R, Tuboi C, Hussain SA (2017) A review of methods for monitoring streamflow for sustainable water resource management. *Appl Water Sci* 7(6):2617–2628
- Dodds WK, Whiles MR (2010) Freshwater ecology: concepts and environmental applications of limnology, 2nd edn. Academic, Burlington
- Doretto A, Bona F, Falasco E, Piano E, Tizzani P, Fenoglio S (2016) Fine sedimentation affects CPOM availability and shredder abundance in Alpine streams. *J Freshw Ecol* 31(2):299–302
- Doretto A, Piano E, Bona F, Fenoglio S (2018) How to assess the impact of fine sediments on the macroinvertebrate communities of alpine streams? A selection of the best metrics. *Ecol Indic* 84:60–69
- Dewson ZS, James ABW, Death RG (2007) A review of the consequences of decreased flow for instream habitat and macroinvertebrates. *J N Am Benthol Soc* 26(3):401–415
- Edwards PM (2016) The value of long-term stream invertebrate data collected by citizen scientists. *PLoS ONE* 11(4):e0153713
- Ellwood ER, Kimberly P, Guralnick R, Flemons P, Love K, Ellis S, Allen JM, Best JH, Carter R, Chagnoux S et al (2018) Worldwide engagement for digitizing biocollections (WeDigBio): the biocollections community's citizen-science space on the calendar. *Bioscience* 68(2):112–124
- Faukner S (2004) Urbanization impacts on the structure and function of forested wetlands. *Urban Ecosyst* 7:89–106
- Firehock K, West J (1995) A brief history of volunteer biological water monitoring using macroinvertebrates. *J N Am Benthol Soc* 14:197–202
- Giller PS (2005) River restoration: seeking ecological standards. Editor's introduction. *J Appl Ecol* 42:201–207

- Graf W, Leitner P, Hanetseder I, Ittner LD, Dossi F, Hauer C (2016) Ecological degradation of a meandering river by local channelization effects: a case study in an Austrian lowland river. *Hydrobiologia* 772:145–160
- Gratton C, Vander Zanden MJ (2009) Flux of aquatic insect productivity to land: comparison of lentic and lotic ecosystems. *Ecology* 90:2689–2699
- Hamilton AS, Moore RD (2012) Quantifying uncertainty in streamflow records. *Can Water Resour J* 37:3–21
- Harding JS, Winterbourn MJ (1995) Effects of contrasting land use on physico-chemical conditions and benthic assemblages of streams in a Canterbury (South Island, New Zealand) river system. *NZ J Mar Freshw Res* 29:479–492
- Harrelson CC, Rawlins CL, Potyondy JP (1994) Stream channel reference sites: an illustrated guide to field technique. U.S. Department of Agriculture, Fort Collins
- Hart DD, Finelli CM (1999) Physical-biological coupling in streams: the pervasive effects of flow on benthic organisms. *Annu Rev Ecol Syst* 30:363–395
- Heino J, Louhi P, Muotka T (2004) Identifying the scales of variability in stream macroinvertebrate abundance, functional composition and assemblage structure. *Freshw Biol* 49:1230–1239
- Hilsenhoff WL (1987) An improved biotic index of organic stream pollution. *Great Lakes Entomol* 20:31–39
- Hilsenhoff WL (1998) A modification of the biotic index of organic stream pollution to remedy problems and permit its use throughout the year. *Great Lakes Entomol* 31(1):1–12
- Horsak M, Bojkova J, Zahradkova S, Omesova M, Helesic J (2009) Impact of reservoirs and channelization on lowland river macroinvertebrates: a case study from Central Europe. *Limnologia* 39:140–151
- Hrodey PJ, Sutton TM, Frimpong EA, Simon TP (2009) Land-use impacts on watershed health and integrity in Indiana warmwater streams. *Am Midl Nat* 161:76–95
- Hupp CR (1992) Riparian vegetation recovery patterns following stream channelization: a geomorphic perspective. *Ecology* 73(4):1209–1226
- Illinois RiverWatch Stream Monitoring Manual (2015) In: Young M (ed) National Great Rivers Research and Education Center, East Alton, IL
- Kairo K, Haldna M, Timm H, Virro T (2017) The effect of channelization on the biological quality of lowland streams using macroinvertebrates as proxies. *Hydrobiologia* 794:167–177
- Kennedy TL, Turner TF (2011) River channelization reduces nutrient flow and macroinvertebrate diversity at the aquatic terrestrial transition zone. *Ecosphere* 2:13
- Laasonen P, Muotka T, Kivijarvi I (1998) Recovery of macroinvertebrate communities from stream habitat restoration. *Aquat Conserv Mar Freshw Ecosyst* 8:101–113
- Lamouroux N, Mérioux S, Dolédec S, Snelder TH (2013) Transferability of hydraulic preference models for aquatic macroinvertebrates. *River Res Appl* 29:933–937
- Landon AC, Kyle GT, van Riper CJ, Schuett MA, Park J (2018) Exploring the psychological dimensions of stewardship in recreational fisheries. *N Am J Fish Manag* 38:579–591
- Lau JK, Lauer TE, Weinman ML (2006) Impacts of channelization on stream habitats and associated fish assemblages in east central Indiana. *Am Midl Nat* 156:319–330
- Lee NM, VanDyke MS (2015) Set it and forget it: the one-way use of social media by government agencies communicating science. *Sci Commun* 37:533–541
- Lepori F, Palm D, Brannas E, Malmqvist B (2005) Does restoration of structural heterogeneity in streams enhance fish and macroinvertebrate diversity? *Ecol Appl* 15:2060–2071
- Mayor SJ, Guralnick RP, Tingley MW, Otegui J, Withey JC, Elmen-dorf SC, Andrew ME, Leyk S, Pearse IS, Schneider DC (2017) Increasing phenological asynchrony between spring green-up and arrival of migratory birds. *Sci Rep* 7:10
- McShea WJ, Forrester T, Costello R, He ZH, Kays R (2016) Volunteer-run cameras as distributed sensors for macrosystem mammal research. *Landsc Ecol* 31:55–66
- Mebane CA (2001) Testing bioassessment metrics: macroinvertebrate, sculpin, and salmonid responses to stream habitat, sediment, and metals. *Environ Monit Assess* 67(3):293–322
- Merritt RW, Cummins KW, Resh VH, Batzer DP (2008) Sampling aquatic insects: collection devices, statistical considerations, and rearing procedures. An introduction to the aquatic insects of North America, 4th edn, Dubuque
- Muotka T, Paavola R, Haapala A, Novikmec M, Laasonen P (2002) Long-term recovery of stream habitat structure and benthic invertebrate communities from in-stream restoration. *Biol Conserv* 105:243–253
- Nakano S, Murakami M (2001) Reciprocal subsidies: dynamic interdependence between terrestrial and aquatic food webs. *Proc Natl Acad Sci USA* 98:166–170
- Poff NL, Allan JD (1995) Functional organization of stream fish assemblages in reaction to hydrological variability. *Ecology* 76:606–627
- Poff NL, Allan JD, Bain MB, Karr JR, Prestegard KL, Richter BD, Sparks RE, Stromberg J (1997) The natural flow regime: a paradigm for river conservation and restoration. *Bioscience* 47:769–784
- Poff NL, Olden JD, Merritt DM, Pepin DM (2007) Homogenization of regional river dynamics by dams and global biodiversity implications. *Proc Natl Acad Sci USA* 104:5732–5737
- Poff NL, Ward JV (1989) Implications of streamflow variability and predictability for lotic community structure—a regional analysis of streamflow patterns. *Can J Fish Aquat Sci* 46:1805–1818
- Power ME, Sun A, Parker G, Dietrich WE, Wootton JT (1995) Hydraulic food-chain models: an approach to the study of food-web dynamics in large rivers. *Bioscience* 45:159–167
- Rempel LL, Richardson JS, Healey MC (2000) Macroinvertebrate community structure along gradients of hydraulic and sedimentary conditions in a large gravel-bed river. *Freshw Biol* 45:57–73
- Resh VH, Brown AV, Covich AP, Gurtz ME, Li HW, Minshall GW, Reice SR, Sheldon AL, Wallace JB, Wissmar RC (1988) The role of disturbance in stream ecology. *J N Am Benthol Soc* 7:433–455
- Schmal RN, Sanders DF (1978) Effects of stream channelization on aquatic macroinvertebrates, Buena Vista Marsh, Portage County, Wisconsin, Washington, D.C.
- Shields FD, Knight SS, Cooper CM (1998) Rehabilitation of aquatic habitats in warmwater streams damaged by channel incision in Mississippi. *Hydrobiologia* 382:63–86
- Storey RG, Wright-Stow A, Kin E, Davies-Colley RJ, Stott R (2016) Volunteer stream monitoring: do the data quality and monitoring experience support increased community involvement in freshwater decision making? *Ecol Soc* 21(4)
- Urban MA (2005) An uninhabited waste: transforming the Grand Prairie in nineteenth century Illinois, USA. *J Hist Geogr* 31:647–665
- Urban MA, Rhoads BL (2003) Catastrophic human-induced change in stream-channel planform and geometry in an agricultural watershed, Illinois, USA. *Ann Assoc Am Geogr* 93:783–796
- USEPA (1990) Freshwater macroinvertebrate species list including tolerance values and functional feeding group designations for use in rapid bioassessment protocols. Assessment and Watershed Protection Division, Washington, D.C
- Wallace JB, Grubaugh JW, Whiles MR (1996) Biotic indices and stream ecosystem processes: results from an experimental study. *Ecol Appl* 6:140–151

- Wallace JB, Merritt RW (1980) Filter-feeding ecology of aquatic insects. *Annu Rev Entomol* 25:103–132
- Wallace JB, Webster JR (1996) The role of macroinvertebrates in stream ecosystem function. *Annu Rev Entomol* 41:115–139
- Warren CE, Wales JH, Davis GE, Doudoroff P (1964) Trout production in an experimental stream enriched with sucrose. *J Wildl Manag* 28:617–660
- Water Resources Development Act (1990) In: Congress U, editor
- Wentworth CK (1922) A scale of grade and class terms for clastic sediments. *J Geol* 30(5):377–392
- Wylie S, Schultz K, Thomas D, Kassotis C, Nagel S (2016) Inspiring collaboration: the legacy of Theo Colborn's transdisciplinary research on fracking. *New Solut* 26:360–388
- Zilliox S, Smith JM (2018) Colorado's fracking debates: citizen science, conflict and collaboration. *Sci Cult* 27:221–241

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.