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Perspective

On the conservation value of historic canals for aquatic ecosystems

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ABSTRACT

While fragmentation and habitat loss due to water infrastructure threaten freshwater biodiversity worldwide, historic canals have the potential to contribute to both cultural heritage and biodiversity conservation. Shifting management objectives regarding historic canals from development to recreation and conservation offer opportunities for achieving conservation targets in these anthropogenic systems. However, managing historic canals often involves multiple objectives (e.g., nature conservation vs historic preservation). We reviewed ecological studies in various types of canal systems, examined the potential of historic canals to contribute to biodiversity conservation, and provided suggestions to promote biodiversity conservation given the opportunities and challenges in canal management. Canal characteristics (e.g., size, main use, surrounding environment, physical and hydrological properties) can be used to qualify or quantify their potential conservation value and risk. Changing management regimes to mimic natural flow, enhance habitat complexity, and modify connectivity could improve ecosystem functions and services in canals. To achieve conservation potential of historic canals, studies are required to fill knowledge gaps and to understand trade-offs among often competing objectives. The use of decision analysis such as structured decision making allows managers to incorporate multiple objectives, evaluate trade-offs, and address uncertainties in historic canal management.

1. Introduction

Water infrastructure projects such as dams and canals have contributed to the development of human civilization but also posed threats to freshwater biodiversity worldwide (Vörösmarty et al., 2010). Anthropogenic barriers, such as dams, have reduced the connectivity of around 50% of global large (> 500 km) rivers (Grill et al., 2019; Fig. 1a), and lowered the range connectivity around 27% for non-diadromous fish and 14% for diadromous fish globally (Barbarossa et al., 2020; Fig. 1 spatial distributions of fragmented rivers and migratory fishes). The loss of connectivity in rivers not only affects freshwater biodiversity by fragmenting and degrading riverine habitats, but also influences terrestrial and marine ecosystems because these barriers reduce connections for material transportation and species movement across ecosystem boundaries (Álvarez-Romero et al., 2011) and aquatic barriers like road-stream crossings might provide novel connections for terrestrial organisms.

Conversely, water infrastructure such as canals can create novel habitats and connections among waterbodies (Figs. 1 and 3). The total length of canals was over 63,000 km globally in the late 20th century (Revenga et al., 2000). While the effects of barriers have been studied from local to global scales, and databases for large and medium dams across the globe have been built and are freely available (http://www.globaldamwatch.org), anthropogenic waterways receive less attention (Shumilova et al., 2018), despite the fact that anthropogenic barriers and connections often occur within the same region (Fig. 1a). Unlike dams that mostly reduce natural connectivity and replace lotic habitats with lentic habitats (Bellmore et al., 2019), the effect of canals on ecosystems varies depending on the characteristics of canals and surrounding environments (Section 3). However, there is a lack of recognition of the biodiversity value in anthropogenic waterways in both research and policy (Chester and Robson, 2013; Clifford and Heffernan, 2018).

The history of human-made waterways is traced back to around 4000 BCE by people in Mesopotamia (Iraq, Iran, and Syria) using waters from the Euphrates and Tigris River for diversion, irrigation, drainage, and navigation (Bjornlund and Bjornlund, 2010; Geyer and Monchambert, 2015). Since then, canals have been built across ancient empires (e.g., Assyria, Egypt, Rome, and eastern China) and modern countries around the world, primarily for development purposes such as water consumption for agriculture and urban water use, transportation, and flood control (Hadfield, 1986; Figs. 1 and 2). Over time,

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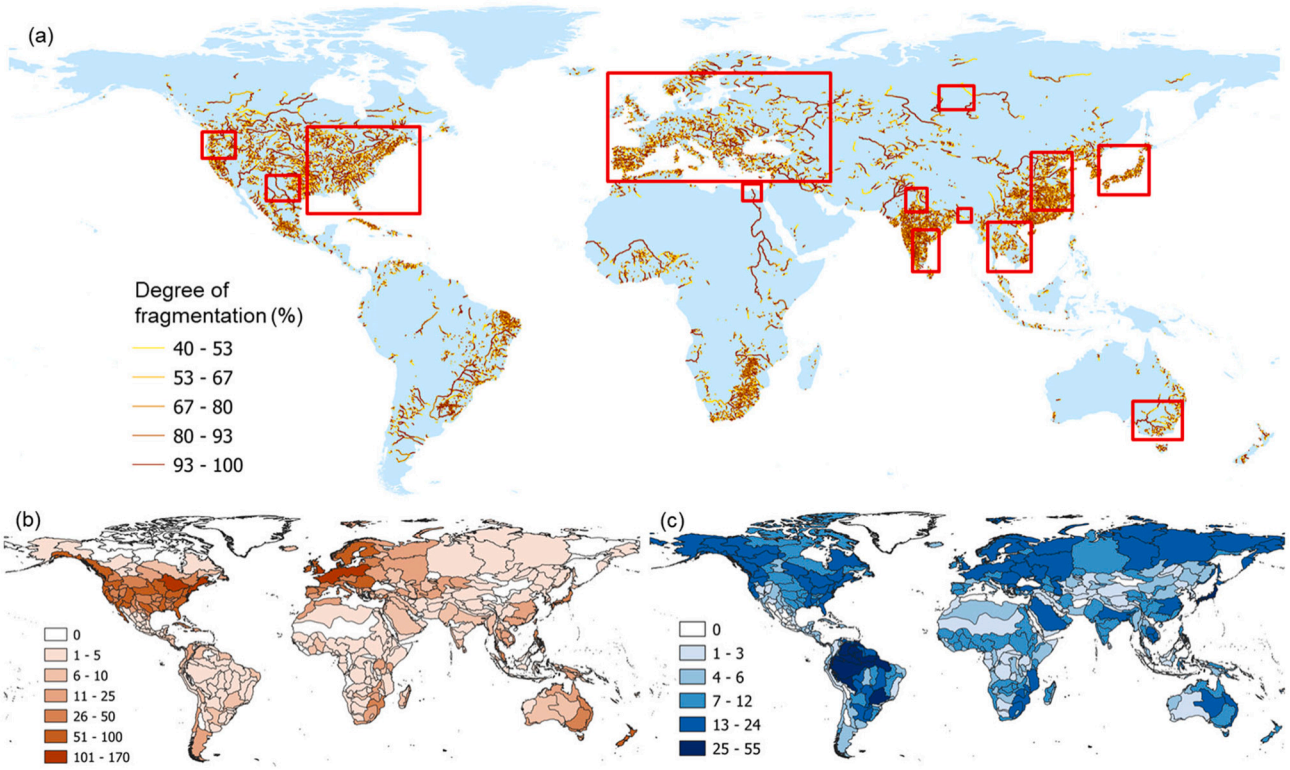

Fig. 1. The distributions of anthropogenic fragmentations and connections (a), numbers of freshwater invasive species (b), and numbers of long-distance (> 100 km) migratory fish species (c) in freshwater ecoregions across the globe. Red boxes in panel (a) indicate areas with major historic canals or canal networks and yellow-brown lines shows rivers with medium to high degree of fragmentation (i.e., calculated as the proportion of river discharge blocked by dams per reach considering the influence of distance from each structure/dam, details see Grill et al., 2019). The data for migratory fish and invasive species were extracted from online database (Hoekstra et al., 2010) and the areas of historic canals were produced based on canals in the literature (e.g., Hadfield, 1986 and Table A1). Some local scale canals or abandoned historic canals that are completely dried out are not included (e.g., canals in South America, Africa, and Middle East). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

these structures may become part of the semi-natural mosaic (i.e., through succession or perception as nature by people) and cultural landscape and provide additional social and cultural value beyond their original function (Clifford and Heffernan, 2018; Hijdra et al., 2014). For example (see Fig. 2), six historic canals have been assigned as UNESCO World Heritage sites (Amsterdam Canal Ring in the Netherlands, Canal du Centre in Belgium, Canal du Midi in France, Grand Canal in China, Pontcysyllte Aqueduct and Canal in UK, and Rideau Canal in Canada) and some canals are considered to be national or regional heritage and historic sites (e.g., the Erie Canal in the US, Trent-Severn Waterway in Canada, Angkor canal system in Cambodia, the Ludwig-Danube-Main-Canal in Germany, and the European Waterways Heritage project).

While some canals are still used and managed for their original intent, many historic canals have been abandoned, partially buried or drained, and have become isolated waterbodies and wetlands. The management of historic canals often includes objectives such as sustaining and promoting ecosystem functions and cultural ecosystem services, which are beyond the original development and economic focused functions and services (Arlinghaus et al., 2002; Guo et al., 2016; Walker et al., 2010). Nevertheless, the balance between positive and negative ecological effects of these systems, and the management implications of potentially competing ecological, economic, and cultural objectives have been little studied.

We sought to address this gap. For our purposes, we defined canals as open (excluding pipes) anthropogenic waterways (excluding channelized rivers), which connect two or more natural or anthropogenic waterbodies with various size, structures, and functions, such as transportation (e.g., navigation canals), defense (e.g., moats), and irrigation (including ditches). We focused on historic canals and related aquatic environments in existence for over 100 years (up to around 2500 years for the Grand Canal in China) because these structures have the greatest likelihood of social and cultural significance. Furthermore, the long-term ecological effects of such infrastructure may gradually stabilize over time (comparing to the suggested timescales for assessing novel ecosystems of 10–100 years; Morse et al., 2014). The social functions and services of canals may also change through time and influence management objectives, for instance, shifting from commercial shipping or defense functions to recreational activities and heritage preservation (Guo et al., 2016; Hijdra et al., 2014; Walker et al., 2010; examples in Fig. 2). Such changes in social function may create opportunities for improving biodiversity conservation, which could be important for certain species particularly when their natural habitats are degraded (e.g., freshwater mussels, Gómez and Araujo, 2008; Sousa et al., 2019b). In addition, historic canals provide an opportunity to study the potential long-term socio-ecological change of ongoing canal construction projects around the world (Shumilova et al., 2018). Canals that primarily link two marine ecosystems such as the Suez and Panama canals are not addressed in this article because connectivity loss and habitat fragmentation due to water infrastructure are more prevalent among freshwaters (i.e., river-river and river-lake connections) or between freshwater and marine systems (i.e., river-sea) than between marine ecosystems (i.e., sea-sea).

Specifically, we (1) examined the background and existing ecological studies regarding the environmental effects of canals, (2) discussed the potential of historic canals for ecological conservation and restoration, (3) assessed opportunities and challenges to promote biodiversity conservation in historic canal management, and (4) provided suggestions for future decision-making to conserve biodiversity in these systems.

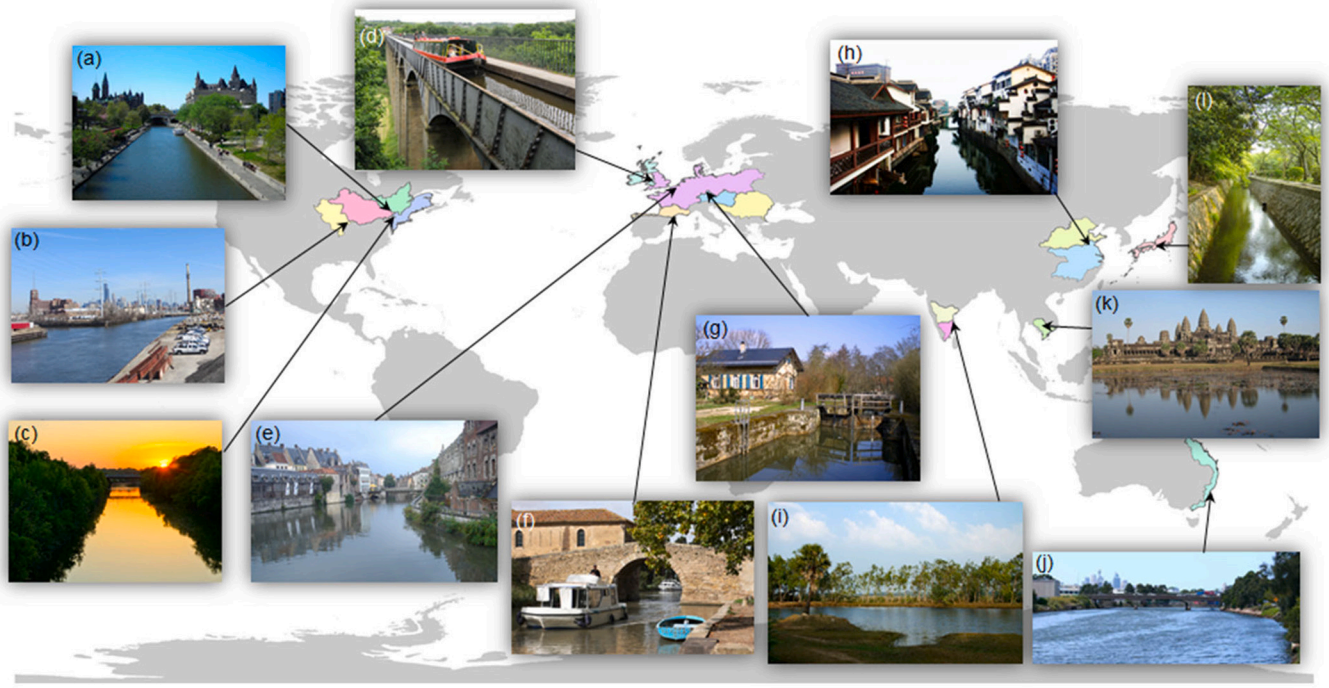

Fig. 2. Examples of historic canals and freshwater ecoregions influenced/connected by these waterways across the globe. (a) Rideau Canal (H Abdallah), (b) Chicago Sanitary and Ship Canal (D Wilson), (c) Erie Canal (J Bates), (d) Pontcysyllte Aqueduct (Arpingstone), (e) Ghent-Terneuzen Canal (C Wolter), (f) Canal du Midi (P Gugerell), (g) Ludwig-Danube-Main-Canal (I Giel), (h) Grand Canal (Legolas1024), (i) Buckingham Canal (M Savage), (j) Alexandra Canal (Pigmypossum), (k) Angkor canals (T Hestnes), (l) Lake Biwa Canal (PRST). Among these canals, four have been assigned as UNESCO World Heritage Sites (a, d, f, h), eight directly connect two freshwater ecoregions (a, b, c, d, g, h, i, l), and nearly all have their primary function changed from transportation and irrigation to recreation (details see Table A3). Photographs were distributed under CC-BY 2.0 (a, b, c, i), 2.5 (f), 3.0 (*h*,*k*) licenses, public domain, or taken by author.

2. The effect of canals on aquatic ecosystems

To explore the potential of historic canals for aquatic ecosystem conservation, we conducted a (not exhaustive) review using keywords representing the structure and ecological conservation to identify relevant literature from Web of Science Core Collection (1995–2020). Structure terms include (*canal$* OR *moat$* OR *ditch** OR "*artificial waterway$*" OR "*anthropogenic waterway$*") and ((*artificial* OR *anthropogenic*) AND (*irrigat** OR *navigat** OR *drain**)) and the ecological conservation terms include (*conserv** OR *restor** OR *rehabi** OR *biodiversity* OR *ecosystem$* OR *habitat$* OR *corridor$*)). We did not include *historic* in the keywords for searching because most ecological studies do not discuss or specify the history or age of the structure, which may indicate a knowledge gap in long-term studies and successions in these anthropogenic waterways. Further filters were used to select studies for aquatic or semi-aquatic species (including riparian plants and waterbirds). Examples in this study were extracted from the final list of 504 publications (Table A1).

Among 504 publications, 48% were conducted in European countries, 31% in the Americas (most in the US and Canada, 26%), 17% in Asia (most in Japan and China, 10%), 3% in Africa and Oceania, and 2% are reviews across continents (Table A1). Nearly all studies (503) collect data from canals and/or ditches (but without clear definition to differentiate these structures) while only one study investigates aquatic species in moat. Sixty-six percent of the studies focus on native species (43% native and 23% native with conservation concern), 19% on alien species, and 14% include alien, native and/or native species with conservation concern. However, besides the examples we used here, most studies focus on the species composition, abundance, distribution, or behaviour in anthropogenic waterways without clearly examining or quantifying the effects on biodiversity.

Negative effects of canals on biodiversity include (i) opening waterways for non-native species and exotic pathogens (Leuven et al., 2009; Rahel, 2013; Fig. 1b; Table A2), (ii) lowering genetic diversity of native species/populations (due to interbreeding between local populations: Muñoz-Ramírez et al., 2015), and (iii) becoming ecological traps (Zeug and Cavallo, 2014). These negative effects mainly result from the novel connection provided by canals between previously separated ecoregions and river basins (Figs. 1 and 2), and the unsuitable habitats canals created for certain species. In contrast, novel connections and habitats may benefit some species by serving as (i) ecological corridors when natural waterways are fragmented (Guivier et al., 2019; Villemey et al., 2018), (ii) alternative migratory pathways (Verhelst et al., 2018; potential for migratory fishes: Fig. 1c), and (iii) refuges from human disturbances or climate change (Cowley et al., 2007; Gómez and Araujo, 2008; Koschorreck et al., 2020; Sousa et al., 2019b). Interestingly, while the stable flow regime in canals provides high quality habitats for the endangered freshwater mussel (*Margaritifera margaritifera*) in most years, extreme drought and lack of water level management in 2017 turned one canal into an ecological trap because it dried almost completely while the other canal and natural waterway still had water flow (Sousa et al., 2019a). This case shows that the benefits and risks of canals to organisms might depend on canal management.

Our understanding of the effects of canals is advancing as a result of empirical case studies across canals in different countries (Table A2). However, these studies mostly focus on a few species of interest at relatively small spatial and temporal scales compared to the size and age of canals. In addition, the ecological condition in canals and connected waterbodies may show complex spatio-temporal dynamics, which depend on the physical, ecological, and socio-economic characteristics in the canal and surrounding areas (Fig. 3). To assess and explore the potential of canals for ecological conservation, integrated studies from local to regional scale will be needed.

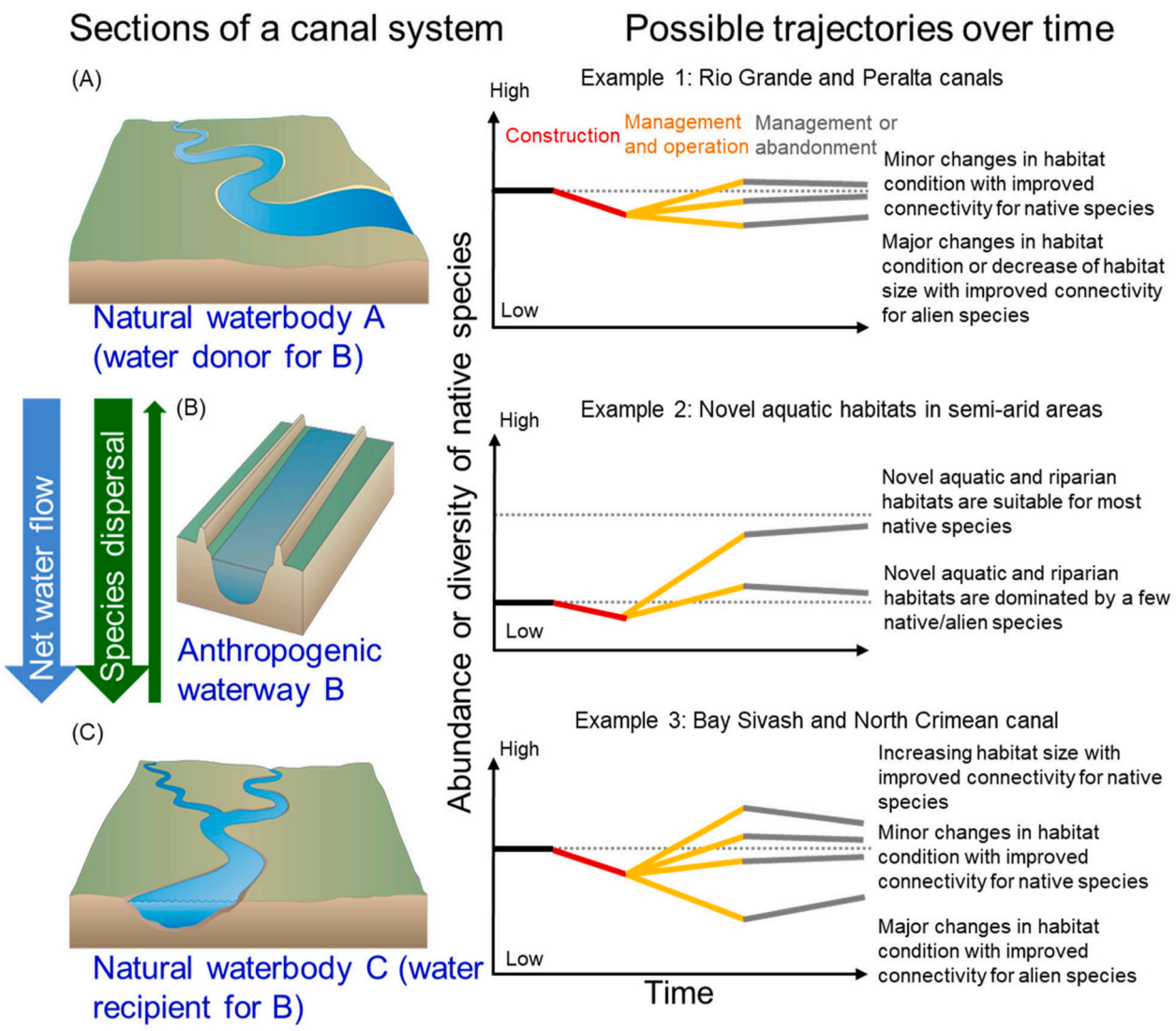

Fig. 3. Possible ecological condition trajectories in different sections of a canal system. Panels on the right indicated hypothetical ecological conditions before (black lines), during (red lines), and after (yellow and grey lines) canal construction. Dotted lines represent the original ecological condition in each section before canal construction (panels A and C, and the lower line in B) or the original condition in connected natural waterbodies (the upper line in B). Canals may have multiple sections A (or B and C) while irrigation canals and moats may not have section C. Waterbody depictions courtesy of the Integration and Application Network (ian.umces.edu/symbols). Example 1: Diverting waters from Rio Grande to Peralta canals reduces available aquatic refuges in the river during drought (Cowley, 2006); Example 2: Novel riparian (Carlson et al., 2019) and wetland habitats created along canals (Hinojosa-Huerta et al., 2002); Example 3: Freshwater discharge from North Crimean Canal turned a hypersaline lagoon (Bay Sivash) into brackish waters and thus reduced the abundance of native zooplankton and meiobenthos. However, the abundance of native species is gradually recovering after the canal closed (Anufriieva and Shadrin, 2020; Sergeeva et al., 2019). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Assessing potential benefits of canals

The characteristics of canals (e.g., physical design) and surrounding environments (e.g., watersheds and socio-ecological contexts) could provide valuable information for assessing the potential (both positive and negative) of canals for biodiversity conservation (Table 1; Clifford and Heffernan, 2018). For example, the size (area or length) of anthropogenic waterways (e.g., section B on Fig. 3) could be used to estimate the size of novel habitats and the size of connected natural waterbodies could indicate the size of new accessible habitats for species/populations in other waterbodies (e.g., section C for species/populations dwell in section A). Furthermore, water quality and chemical features such as chlorophyll *a* concentration, turbidity, and salinity and species pools in connected natural waterbodies could be used to identify species that thrive in canals (Zhao et al., 2018). The potential of canals as migration alternatives for migratory species could be assessed by comparing the cumulative passability of barriers (e.g., dams, weirs, locks, and sluices) between natural and anthropogenic waterways. For example, Albert Canal might be used as a migration alternative for European eels because the hydropower plants along the natural waterway (i.e., Meuse River) cause substantial mortality rates for migrating eels (Verhelst et al., 2018). However, the lack of directed current in combination with monotonous littoral habitats may make long artificial canals de facto migration barriers for some fish species (Wolter and Vilcinskas, 1998). Therefore, hydrological properties that may guide or trigger fish migration need to be taken into consideration (Table 1).

In general, the original purpose of canals and associated management and human usage schemes fundamentally determines their characteristics and thus influences their potential for biodiversity conservation. For example, canals built for defense purposes (e.g., moats) are usually local and disconnected, while irrigation canals (e.g., canal

Table 1
The characteristics of canals and surrounding socio-ecological contexts that could be used to estimate the potential conservation value and risk of canals. Examples can be found in the main text. We assigned characteristics into four groups, setting, time, physical design, and management based on Clifford and Heffernan, 2018.

Characteristics	Estimating potential conservation value
Setting: the capacity of the waterway influenced by surrounding environments	
Species in surrounding and connected natural habitats	Potential immigrants or invaders from surrounding species pools. Species traits such as habitat requirements, movement/dispersal ability and pattern, trophic niche can further refine the result.
Land-use pattern	Potential habitat or migration alternative. Land-use pattern like urban, agriculture, or forestry in surrounding areas could have a strong influence on species composition and ecosystem services in aquatic and riparian systems
Connected waterbody size	Potential size of newly accessible habitat for previously isolated species or populations.
Connections with other canals, canal networks, or port facilities	Potential dispersal route for non-native or unwanted species through waterways, riparian corridors, or human activities.
Physical design: the capacity of the waterway influenced by its own structures and features	
Canal size	Potential size of novel riparian and aquatic habitats.
Physical properties	Potential riparian and near shore habitat: bank and shoreline structure; potential benthic habitat: depth, substrate material, bottom structure, sediment type.
Hydrological properties	Potential habitat or migration alternative: water supply (volume, permanency), water flow (direction, rate, average, and seasonal variation), water temperature (average, seasonal variation). For example, lotic habitats are usually found in irrigation canals while in navigation canals lentic habitats dominate due to different flow and purposes.
Length and passability of canal and nearby natural waterway and the location of canal within migration route	Potential of being migratory alternative for migratory species: number and types of natural (waterfalls, rapids) or anthropogenic barriers (dams, weirs, locks, sluice, hydropower facilities), and fish passages.
Water quality and chemical features	Potential habitat or migration alternative: nutrient and pollutant concentration, clarity, dissolved oxygen, and salinity. Note this characteristic is also influenced by surrounding land-use.
Time: the past of the waterway	
Canal age and management history	Proxy for natural succession and potential habitat quality and diversity. Old canals with limited disturbances from historical management may contain habitats more similar to natural waterbodies than canals with a shorter age and under intensive management in the history.
Ongoing management: the future of the waterway	
Main use	Actual current main use: set boundary conditions/restrictions for ecological enhancement; possible future main use should be considered if needed (changing management plans or climate). Conflicts between objectives and the multifunctionality of the canal (e.g., recreation, irrigation, transportation, and heritage) for different users and stakeholders should be considered.
Operation and management regime	Potential habitat or migration alternative: riparian and waterway vegetation management, locks, hydropower facilities, and water intake devices operation regime (structure, frequency, timing), water level and flow control.
Capacity to manipulate water level and flow	Potential climate and extreme weather refuge. Create habitable environment for human society and target species under changing climate or extreme events.

and ditch networks) tend to be well connected as networks but are relatively narrow and shallow and thus subject to succession and disappearance if unmaintained. In contrast, navigation canals are comparably wide, and therefore may persist longer and provide relatively large aquatic habitats. While disconnected or small-size waters may serve as refuges for invertebrates and amphibians from predation, well connected and large canals could provide habitats and corridors for large organisms like fish and waterbirds (Chester and Robson, 2013; Clifford and Heffernan, 2018). The trajectory of ecological condition in canals also varies with management intensity because some management actions like dredging and mowing may interrupt natural succession (Clifford and Heffernan, 2018; Dorotovičová, 2013; Fig. 3, see next section).

The dispersal of native and non-native aquatic species in canal systems may be asymmetrical based on the direction of water flows, the species' ability to swim against the flow (Fig. 3), and the ecological traits of native and non-native species (e.g., generalist and specialists). Carefully examining the ecological traits of species from surrounding species pools (e.g., species assemblages in canals and connected habitats) and the characteristics of these species in light of canal management regimes could help identify species that might benefit from novel canal habitats (Daniels, 2001). For example, in the central European bioregion, non-native freshwater fish usually have smaller body size, shorter life span, earlier maturation, and broader diet breath than native species (Grabowska and Przybylski, 2014). Similarly, species with small size, high abundance, migratory behaviour, and generalist habitat preferences are more likely to use canals as migration routes or dispersal corridors (Schmidt et al., 2019).

In addition, surrounding landscape and land-use patterns also play important roles in aquatic and riparian communities within both natural rivers and artificial canals (Carlson et al., 2019; Clifford and Heffernan, 2018). For example, riparian biodiversity along the Dortmund–Ems Canal in Germany is positively related to landscape heterogeneity (Harvolk et al., 2014). Riparian corridors along canals can also provide habitat connectivity for non-aquatic taxa (Fremier et al., 2015).

Finally, for canals within a regional network across multiple basins and freshwater ecoregions, such as inland waterway networks in the eastern North America and Laurentian Great Lakes, Europe, Russia, and China, there is an elevated risk of spread of non-native species (Daniels, 2001; Leuven et al., 2009; Mills et al., 1996; Fig. 1b). The direction and intensity of shipping and the location of human activities such as ports, marinas, cities, lock and dams, fishing grounds, and aquaculture facilities along canals and throughout canal networks could provide valuable information to predict the spatial distribution of non-native species. By qualifying (e.g., types of novel habitats) and quantifying (e.g., size of novel habitat) the potential benefit and risk of canals, managers could estimate and compare the cost-effectiveness of different management actions for biodiversity conservation or prioritize canals/canal sections for conducting on-ground survey or conservation actions.

4. Challenges in managing historic canals for biodiversity conservation

After assessing the potential of canal systems for biodiversity conservation, some changes may need to be implemented to improve the current condition of canals for aquatic communities or species of conservation or management interest. Different management actions will

be required depending on the characteristics of canals (see Section 2) and the objectives of management for biodiversity conservation and other purposes. For instance, irrigation canals might suffer from fish entrainment due to the complex canal and ditch networks (Roberts and Rahel, 2008), nutrient loading and sedimentation due to nearby agriculture activities and relatively small channel size (Dollinger et al., 2015), while the main pressures in navigation canals may be physical disturbances such as wake wash by shipping and boating (Zajicek and Wolter, 2019), lack of habitat structures, and poor water quality (Daniels, 2001; Wolter, 2001).

For abandoned canals, lack of maintenance over centuries may allow the development of mature successional stages of high conservation value, especially for riparian and aquatic vegetation as well as limnophilic fish and semiaquatic birds, mammals, and invertebrates. For instance, in Slovakia, the aquatic macrophyte diversity is comparable or even higher in some canals than natural waters because low management intensity allows natural succession and low hydrologic dynamics (Dorotovičová, 2013). Nevertheless, management actions such as maintaining water level during drought or removing non-native species might be required based on the need of species of conservation interest (Chester and Robson, 2013; Sousa et al., 2019a). For canals that are still heavily used, actively improving water quality and managing hydrological and physical characteristics may be necessary to mimic the condition of natural habitats and migration pathways (Verhelst et al., 2018). This may be a challenge in areas where behaviour changes and/or investments are required of property owners or local governments. Sustaining environmental flows in canals during extreme weather like abnormal precipitation periods or prolonged drought due to climate change could offer refuges for aquatic species (Chester and Robson, 2013; Cowley et al., 2007). To protect native species and other species of interest while preventing biological invasion, connectivity may need to be controlled by modifying the structure or operation mode of locks (Silva et al., 2017; Verhelst et al., 2018) and hydropower facilities, changing draining time, and building selective passages and barriers (Rahel, 2013). Furthermore, increasing habitat complexity on the bottom and bank (especially given that many canals are lined with concrete), such as reducing the frequency of sediment clearing on the bottom (Chester and Robson, 2013) and creating shallow, wave protected, littoral areas along the shoreline (Weber et al., 2017), could diversify available habitats and thus enhance biodiversity in canals (Harvolk et al., 2014).

While methods described above may help a canal approach its ecological potential, some challenges might influence the effectiveness and applicability of conservation actions. The first type of challenge comes from knowledge gaps about how communities or species of interest use, adapt, and respond to artificial habitats and canal operation regimes (Koschorreck et al., 2020). Studies are required to examine the relationships between management actions, canal characteristics, and ecological variables in the system and the relationships between ecological variables and specific management objectives (examples in Fig. 4). While studies have been conducted to understand the species and functional diversity (Carlson et al., 2019; Walker et al., 2010; Wolter, 2001), fish recruitment (Arlinghaus et al., 2002), and animal movement (Hooley-Underwood et al., 2018; Vergeynst et al., 2019) in anthropogenic waterways (also see Table A2), systematic reviews will be required to evaluate the effectiveness of conservation actions by integrating and analyzing available data from previous studies in a repeatable way (Cooke et al., 2017). However, the number of studies on canal ecology is relatively small and most studies focus on canals in North America and Europe with a few species of interest (Table A1), regardless of the worldwide distribution of historic canals, and the unique management challenges and ecological contexts each canal faces (Fig. 1). Large-scale studies and centralized inventories (like global database for dams) can benefit future management because the effects and potential of canals could influence multiple watersheds, ecoregions, and jurisdictions.

More empirical, field-based studies are also required to quantify the ecological effects of different canal operation and management regimes for objectives other than biodiversity conservation, such as management for navigation, irrigation, recreational activities, or historic conservation. Studies on cumulative effects when multiple human disturbances and management actions occur simultaneously in the same canal system are generally lacking (for an exception see Verhelst et al. (2018), which examines the cumulative effect of multiple locks on the migration of European eel). Expert elicitation and adaptive management could be used to facilitate decision making in areas lacking empirical data (Bower et al., 2018) and to seek balance in the case of competing objectives. Bayesian networks could be particularly useful for assessing the passability of different structures, such as locks, dams, and sluices (similar to Wilkes et al. (2018)), and for identifying the suitability of novel habitat (Tantipisanuh et al., 2014) for native and non-native species in canal systems. In general, Bayesian networks are graphical models showing probabilistic relationships between variables. For example, a Bayesian network can show how reducing lock maintenance and operation frequency influence historic structure maintenance, aquatic habitat connectivity (and subsequently the populations of native and alien species), and the satisfaction of resources users like fishers and boaters (Fig. 4). Key advantages of Bayesian networks are that they can incorporate expert knowledge when empirical data are limited, and include new data when it became available through adaptive management (Martin et al., 2012).

Another type of challenge in canal management comes from the potential conflicts among management objectives and constraints in socio-economic and political contexts. For historic reasons, canals are often located in populated areas (e.g., navigation canals that contribute to the development of villages and cities along the waterways) or in landscapes popular for aesthetic and recreational purposes. Canals also frequently stretch over multiple jurisdictions and geographic regions, drawing in diverse stakeholders (Llausàs et al., 2020). This complexity can cause conflict due to competing objectives and values among management authorities and stakeholder groups or even within each group. For example, conflicts between water resource and transportation departments have been observed in managing the Grand Canal, China, because of the differences in management objectives and regulations (Wang, 2012). While the management goal for the Rideau Canal, Canada, is to preserve both the cultural and natural values while allowing for sustainable development and recreational use (Walker et al., 2010), lock operation for recreational boating during summer months might increase the potential risk of invasion by species such as Asian carp species (*Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, *H. nobilis*). Increasing cultural ecosystem services such as recreational boating could reduce the diversity of fish communities and erode bank habitats (Zajicek and Wolter, 2019). Maintaining a stable and slow flow in canals for navigation might also create habitats unsuitable for rheophilic and lithophilic species. Besides expected functions and services, historic assets such as old locks, dams, and embankments also require maintenance and protection. Conserving historic infrastructure, which has become enmeshed in social identity for local communities, could hinder restoration plans for migratory fish (Fox et al., 2016). Preserving historic embankments may limit the capacity for improving riparian habitat diversity and shoreline development by property owners. Furthermore, the long history of anthropogenic infrastructure may make some stakeholders consider this novel ecosystem to be part of nature, thus evoking strong conservation ethos reactions to proposed changes in management (Fox et al., 2016).

Lastly, management authorities might receive funds from different sources with associated constraints on how they can be spent (Hijdra et al., 2014; Wang, 2012). For instance, funds for repairing and renewing dams and locks might only be used to improve navigation relevant functions regardless of other values and purposes linked to these structures like historic preservation and biodiversity conservation (Hijdra et al., 2014). Because of the long lifespan of some canal assets

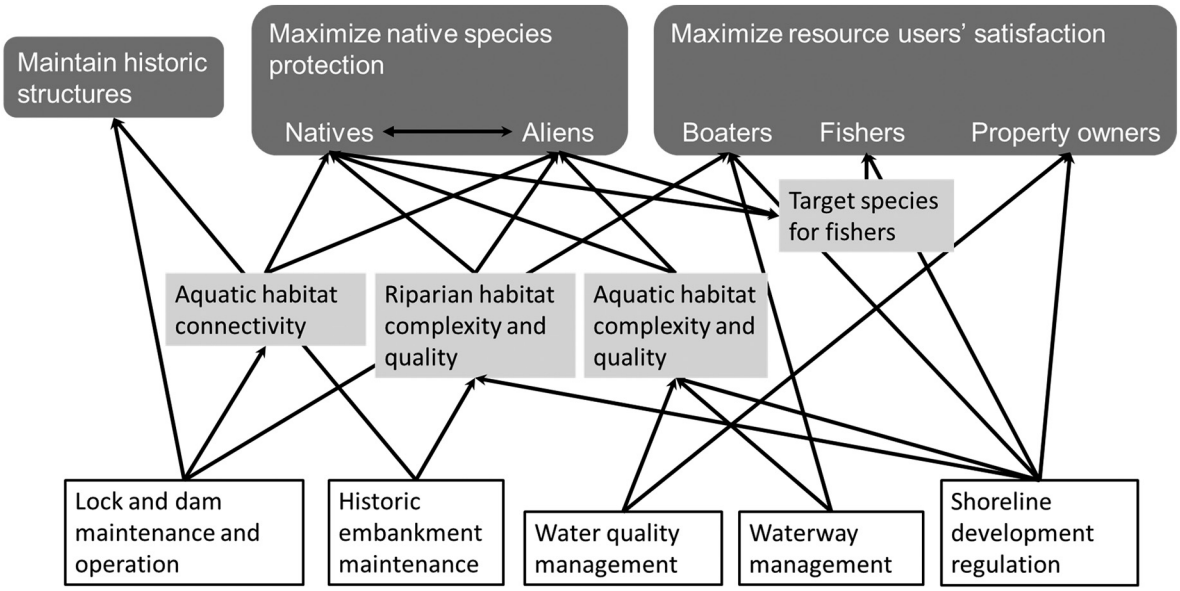

Fig. 4. An example of an influence diagram showing possible relationships (influences) between management actions (white boxes) and objectives (dark grey boxes). Light grey boxes are ecological variables influenced by different management actions. Relationships (arrows) could be qualified or quantified through Bayesian networks, empirical models, and expert elicitation.

(Hijdra et al., 2014), the investment cycle for maintenance might be too long to make any changes that could control non-native species. For example, the investment cycle for historic waterway maintenance in the Netherlands (Hijdra et al., 2014) and the Federal Energy Regulatory Commission licenses for hydropower projects in the US could be up to 50 years long, which may delay major changes to the infrastructure such as building selective passage for aquatic species. For canals that reach across multiple jurisdictions, the development and implementation of new management regimes might be difficult because of institutional barriers and different mandates and regulations among management authorities. Decision makers within and among government agencies also need to identify potential stakeholder groups that might be influenced by or have the ability to influence the implementation of new management actions. For example, focusing on the economic interest of one group of stakeholders caused the decommission of historic canals in the Lower Ter River, Spain, which negatively affected downstream ecosystems and the interest of other stakeholders (Llausàs et al., 2020). In some cases, the preservation of a canal, or parts of a canal, emerge bottom up from local groups mainly interested in cultural or technical heritage assets (e.g., canal/historical societies), which may not incorporate ecological considerations (Fox et al., 2016).

5. Reconciling conservation potential and challenges

A structured decision making framework for canal management decisions can help in cases where multiple authorities or stakeholders with conflicting objectives are involved in canal management decisions. Structured decision making helps to incorporate different objectives and examine trade-offs among management actions in an explicit and transparent way (examples see Fig. 5; Bower et al., 2018; Gregory et al., 2012). The structured decision making framework includes six steps: (1) problem framing, (2) determining objectives, (3) identifying alternatives, (4) estimating consequences, (5) evaluating trade-offs, and (6) deciding and taking actions (Fig. 5; Bower et al., 2018; Gregory et al., 2012). Different objectives and values of historic canals such as navigation, irrigation, hydropower, flood control, social identity, aesthetics, historic/heritage, recreation, and ecology should be defined in the first two steps (Fig. 5: steps 1 and 2). Key stakeholder groups may be identified by methods such as social network analyses (Guerrero et al., 2013).

Next, trade-offs among objectives could be examined and discussed by decision makers and stakeholders during the decision-making process (Fig. 5: steps 3 to 5). Conceptual models such as influence diagrams and decision trees that represent possible relationships between management actions and objectives could be developed through participatory modelling by decision makers and stakeholders (example see Fig. 4; Robinson and Fuller, 2017). Qualitative or quantitative models, such as Bayesian networks, empirical models, and expert elicitation could be used to reveal and examine the interactions and trade-offs among objectives (Robinson and Fuller, 2017). For example, while building fish bypasses or modifying lock operations (e.g., frequency and timing) may increase the connectivity for native species, the risk of biological invasion considering the potential habitat/production for both natives and non-natives after implementation should be estimated. The influence of building passages or changing lock operation on other management objectives such as navigability and historic lock maintenance, also require examination. In addition, draining, controlling vegetation (both aquatic and riparian), and clearing sediment (e.g., dredging) are commonly implemented to maintain navigability and protect historic structures of canals. However, the effects of these management actions on natural succession, bank and bottom dwelling invertebrates and fish, and vegetation communities should be assessed (Chester and Robson, 2013; Harvolk et al., 2014; Sousa et al., 2019b). Subsequently, tools, such as multi-objective optimization and trade-off analysis, could be used to facilitate decision-making processes by finding optimal or near-optimal solutions among competing objectives in canal management similar to studies for watershed restoration and water management (Martin et al., 2016; Poff et al., 2016). For example, these tools could identify management actions that collectively could achieve management objectives for historic structure protection, target species/habitat conservation, and recreational activities while minimizing the overall economic cost.

In some cases, synergistic effects among objectives might create win-win situations. For instance, by redesigning waterfront landscapes and establishing wetland systems, both ecosystem (provision, regulating, and supporting services) and cultural services (aesthetic, recreation and tourism, education, and heritage) could be improved in the Xianghe section of Grand Canal, China (Guo et al., 2016). The structured decision making framework provides decision makers and stakeholders with a structured and explicit way to incorporate multiple

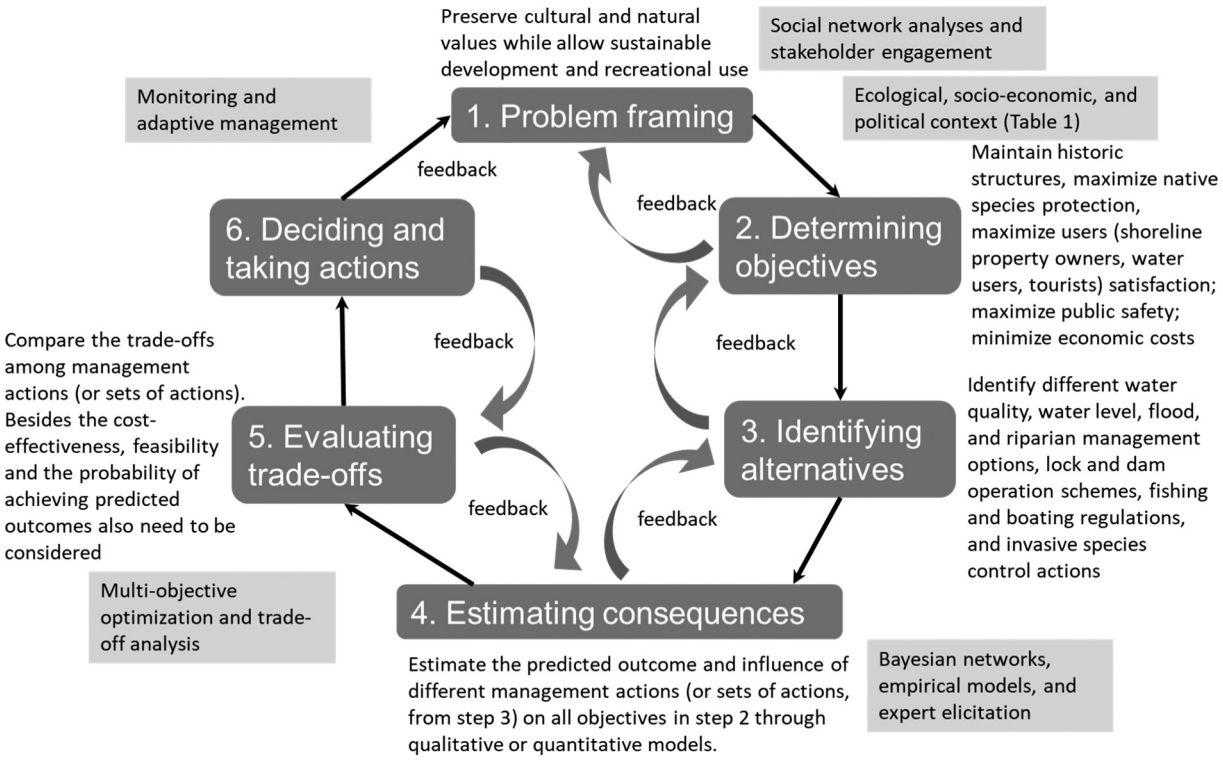

Fig. 5. Example of using structured decision making framework to address multiple objectives in historic canal management. Dark grey boxes are steps in the structured decision making framework, light grey boxes are tools or models could be used to facilitate decision making processes, and opened boxes are examples in each steps.

objectives and assess trade-offs among them, which could be critical for finding such win-wins. Furthermore, uncertainties from knowledge gaps can be modelled in the step that estimates consequences (step 4 in Fig. 5) and can be addressed through learning and adaptive management (feedback arrow from step 6 back to step 1 in Fig. 5).

6. Synthesis and conclusion

Despite the potential contribution of anthropogenic waterways to biodiversity conservation, these habitats are unlikely to provide the ecological functions and services of natural waterbodies (Carlson et al., 2019; Chester and Robson, 2013; Harvolk et al., 2014). Therefore, managers should consider conserving or restoring natural waterbodies whenever possible. Nevertheless, in places where natural waterbodies are highly degraded and restoration measures are not feasible because of ecological, socio-economic, cultural, and political constraints, conserving or restoring the ecosystem in anthropogenic waterways could be a valuable alternative. Trade-offs should be examined if the canal or the operation of the canal may be one of the causes of the degradation of natural waterbodies (e.g., alter natural flow regime). While the recognition of the heritage value of some old canals increases over time, these anthropogenic waterways also become more integrated into the surrounding ecosystem. Therefore, improving and protecting the ecological condition of historic canals could enhance both cultural and natural ecosystem functions and services they provide. For example, management plans for Rideau Canal (Walker et al., 2010) and the Grand Canal (Guo et al., 2016) include objectives addressing cultural and natural issues. In Europe, the obligation of environmental improvement explicitly has been extended by the Water Framework Directive (WFD, 2000/60/EC) to heavily modified and artificial waterbodies (Clifford and Heffernan, 2018).

In conclusion, while many natural waterbodies become fragmented by artificial barriers in rivers and streams, the transition of functions and services provided by historic canals over time opens windows to incorporate biodiversity conservation into canal management. Enhancing biodiversity might also attract additional resources, which at the same time help stop further abandonment and protect cultural heritage. The integration of historic canals into natural and cultural landscapes may raise challenges for management because of the knowledge gaps in ecological response and potential conflicts and constraints in socio-economic and political contexts. The use of structured decision making processes provides an opportunity for decision makers and stakeholders to incorporate multiple objectives and evaluate trade-offs (Fig. 4). We contend that even in canals for which management objectives exclude natural heritage, that there are opportunities for conservation gains to be made.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by the NSERC Strategic Partnership and the Environment and Climate Change Canada.

Appendix A. Appendix A

Appendix Table A1

Author	Year	Title	Structure	Species/community	Location	Location 2	Row labels	Count of structure				
Son, MO et al	2020	Caspian invaders vs. Ponto-Caspian locals - range expansion of invasive macroinvertebrates from the Volga Basin results in high biological pollution of the Lower Don River	Canal	Alien	Ponto-Caspian region	EURO	both	30				
Bazzuri, ME et al	2020	Zooplankton-population dynamics in the Salado-River basin (Buenos Aires, Argentina) in relation to hydraulic works and resulting wetland function	Canal	Native	Argentina	SAm	canal	270				
Miyu, TR et al	2020	Modern Farming Practices in Paddy Fields Negatively Affect an Endemic Frog, Glandirana susurra, in Japan	Ditch	Native	Japan	JP	ditch	203				
Lujan, NK et al	2020	Is Niagara Falls a barrier to gene flow in riverine fishes? A test using genome-wide SNP data from seven native species	Canal	Native	Canada-US	NAm	moat	1				
van Keeken, OA et al	2020	Behavioral responses of eel (*Anguilla anguilla*) approaching a large pumping station with trash rack using an acoustic camera (DIDSON)	Canal	Native	Netherlands	EURO	Total	504				
Ljevnaic-Masic, B et al	2020	Assessment of the habitat conditions of a rare and endangered inland saline wetland community with *Bolboschoenus maritimus* (L.) Palla dominance in Southeastern Europe: the effects of physical-chemical water and soil properties	Canal	Conservation concern	Serbia	EURO						
Sa-Nguansil, S & Wangkulangkul, K	2020	Salinity tolerance in different life history stages of an invasive false mussel *Mytilopsis sallei* Recluz, 1849: implications for its restricted distribution	Canal	Alien	Thailand	SEA						
Neiber, MT et al	2020	Not a marginal loss: genetic diversity of the endangered freshwater snail Melanopsis etrusca (Brot, 1862) from thermal springs in Tuscany, Italy	Canal	Conservation concern	Italy	EURO	Row Labels	Count of species/community				
Zeng, SL et al	2020	Effects of road ditches on the vegetation composition in a saline environment	Ditch	Alien/native	China	EAs	alien	98				
Foubert, A et al	2020	How intensive agricultural practices and flow regulation are threatening fish spawning habitats and their connectivity in the St. Lawrence River floodplain, Canada	Ditch	Conservation concern	Canada-US	NAm	alien/native	49				
Luke, SH et al	2020	Complexity within an oil palm monoculture: The effects of habitat variability and rainfall on adult dragonfly (Odonata) communities	Ditch	Native	Indonesia	SEA	all (alien, native, native with conservation concern)	24				
Koschorreck, M et al	2020	Hidden treasures: Human-made aquatic ecosystems harbour unexplored opportunities	Ditch	Native	Europe	EURO	conservation concern	115				
Musters, CJM et al	2019	Partitioning the impact of environmental drivers and species interactions in dynamic aquatic communities	Ditch	Native	Netherlands	EURO	native	218				
Sousa, R et al	2019	Water mill canals as habitat for *Margaritifera margaritifera*: Stable refuge or an ecological trap?	Canal	Conservation concern	Portugal	EURO	Total	504				
Glon, MG et al	2019	Lacunicambarus dalyae: a new species of burrowing crayfish (Decapoda: Cambaridae) from the southeastern United States	Ditch	Native	US	NAm						
Sakaris, PC et al	2019	Ontogenetic and Temporal Diet Shifts of the Invasive Asian Swamp Eel in South Florida	Canal	Alien	US	NAm						
Maciaszek, R et al	2019	New records of the invasive red swamp crayfish *Procambarus clarkii* (Girard, 1852) (Decapoda: Cambaridae) from Poland	Canal	Alien	Poland	EURO	Row Labels	Count of location 2				
Syarki, MT	2019	The Invasion of the American Rotifer *Kellicottia bostoniensis* (Rousselet, 1908) (Rotifera: Brachionidae) into Vygozersky Reservoir (Republic of Karelia, Russia)	Canal	Alien	Russia	RU	BER	1	ATLANTIC	BER	1	1
Sousa, R et al	2019	Refuge in the saqya: Irrigation canals as habitat for one of the world's 100 most threatened species	Canal	Conservation concern	Morocco	NAf	BI	41	EUROPE	EURO	198	241
Musters, CJM et al	2019	Spatial and temporal homogenization of freshwater macrofaunal communities in ditches	Ditch	Native	Netherlands	EURO	CAm	4		BI	41	
Lopez-Rodriguez, MJ et al	2019	Effect of shifts in habitats and flow regime associated to water diversion for agriculture on the macroinvertebrate community of a small watershed	Ditch	Native	Spain	EURO	CAs	1		RU	2	

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Appendix Table A1 (*continued*)

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Evans, KL & Montagnes, DJS	2019	Freshwater sponge (Porifera: Spongillidae) distribution across a landscape: Environmental tolerances, habitats, and morphological variation	Canal	Alien/native	UK	BI	EAf	2	AMERICAS	NAm	133	155
Geladi, I et al	2019	100-year time series reveal little morphological change following impoundment and predator invasion in two Neotropical characids	Canal	Alien/native	Panama	CAm	EAs	17		CAm	5	
Ohba, S et al	2019	Effects of irrigation system alterations on the trophic position of a threatened top predator in rice-field ecosystems	Ditch	Conservation concern	Japan	JP	EURO	194		SAm	17	
Wu, P et al	2019	Responses of plant distributions in drainage ditch banks to soil salinity in an arid agricultural irrigation region of Northwest China	Ditch	Native	China	EAs	EURO, ASIA	1	ASIA	EAs	17	86
Li, B et al	2019	Breeding habitat influences abundance and body condition of rice frog (*Fejervarya multistriata*) in agricultural landscape of Shanghai, China	Ditch	Native	China	EAs	EURO, CAs	1		SEA	12	
Cejka, T	2019	Freshwater Molluscan Fauna in Danubian Drainage Ditches in Slovakia: High Species Richness and Conservation Value	Ditch	Conservation concern	Slovakiaia	EURO	EURO, MEa	1		CAs	2	
Gavioli, A et al	2019	Diversity patterns of native and exotic fish species suggest homogenization processes, but partly fail to highlight extinction threats	Canal	Alien/native	Italy	EURO	Global	11		MEa	6	
Giuliano, D & Bogliani, G	2019	Odonata in rice agroecosystems: Testing good practices for their conservation	Both	Native	Italy	EURO	JP	36		ASIA	1	
Nolan, ET & Britton, JR	2019	Spatial variability in the somatic growth of pikeperch *Sander lucioperca*, an invasive piscivorous fish	Canal	Alien	UK	BI	MEa	5		JP	36	
Collins, SJ et al	2019	Life in the slow drain: Landscape structure affects farm ditch water quality	Ditch	Native	Canada	NAm	NAf	7		SAs	12	
Cebulska, KD & Krodkiewska, M	2019	Further dispersion of the invasive alien species *Corbicula fluminea* (O. F. Muller, 1774) in the Oder River	Canal	Alien	Poland	EURO	NAm	132	AFRICA	EAf	2	9
Paller, VGV et al	2019	Cercarial fauna of freshwater snails in selected agricultural areas in Laguna, Philippines	Canal	Native	Philippines	SEA	NAm, CAm	1		NAf	7	
Guivier, E et al	2019	Canals as ecological corridors and hybridization zones for two cyprinid species	Canal	Native	France	EURO	NZ	1	OCEANIA	OZ	5	6
Buczynska, E & Buczynski, P	2019	Survival under anthropogenic impact: the response of dragonflies (Odonata), beetles (Coleoptera) and caddisflies (Trichoptera) to environmental disturbances in a two-way industrial canal system (central Poland)	Canal	Native	Poland	EURO	OZ	5		NZ	1	
Marchessaux, G et al	2019	THE FRESHWATER JELLYFISH CRASPEDACUSTA SOWERBII LANKESTER, 1880: AN OVERVIEW OF ITS DISTRIBUTION IN FRANCE	Canal	Alien	France	EURO	RU	1	GLOBAL	global	11	11
Krug, P et al	2019	Salicaceae afforestations: advantage or disadvantage for Neotropical otter in its southernmost distribution?	Canal	Conservation concern	Argentina	SAm	RU, EURO	1				
Carlson, EA et al	2019	Irrigation canals are newly created streams of semi-arid agricultural regions	Canal	Alien/native	US	NAm	SAm	17				
Svedarsky, D et al	2019	Integrated management of invasive cattails (Typha spp.) for wetland habitat and biofuel in the Northern Great Plains of the United States and Canada: A review	Ditch	Alien	Canada-US	NAm	SAs	12				
Barua, P et al	2019	Abundance of Macrobenthos with Special Reference to Some Physico-Chemical Parameters of South-Eastern Coastal Area, Bangladesh	Canal	Native	Bangladesh	SAs	SEA	12				
Hunter, ME et al	2019	Environmental DNA (eDNA) Detection of Nonnative Bullseye Snakehead in Southern Florida	Canal	Alien	US	NAm	Total	504				
Goetz, FA & Quinn, TP	2019	Behavioral thermoregulation by adult Chinook salmon (*Oncorhynchus tshawytscha*) in estuary and freshwater habitats prior to spawning	Canal	Native	US	NAm						
Kulkoyluoglu, O et al	2019	Correlational patterns of species diversity, swimming ability and ecological tolerance of non-marine ostracoda (Crustacea) with different reproductive modes in shallow water bodies of agri region (Turkey)	Ditch	Native	Turkey	MEa						
Steele, K et al	2018	Variation between European eel Anguilla anguilla (L.) stocks in five marshes of the Thames Estuary (United Kingdom)	Ditch	Conservation concern	UK	BI						
Bubikova, K & Hrivnak, R	2018	Relationships of macrophyte species richness and environment in different water body types in the Central European region	Canal	Native	Slovakiaia	EURO						

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Remm, L et al	2018	Amphibians in drained forest landscapes: Conservation opportunities for commercial forests and protected sites	Ditch	Native	Estonia	EURO		
Pearl, CA et al	2018	Late-Season Movement and Habitat Use by Oregon Spotted Frog (*Rana pretiosa*) in Oregon, USA	Ditch	Conservation concern	US	NAm		
Verhelst, P et al	2018	European silver eel (Anguilla anguilla L.) migration behaviour in a highly regulated shipping canal	Canal	Conservation concern	Belgium	EURO		
Vaikre, M et al	2018	Functional Assemblages of Macroinvertebrates in Pools and Ditches in Drained Forest Landscape	Ditch	Native	Estonia	EURO		
Jimenez-Contreras, J et al	2018	Diversity of Rotifera (Monogononta) and Egg Ratio of Selected Taxa in the Canals of Xochimilco (Mexico City)	Canal	Native	Mexico	CAm		
Canova, L & Balestrieri, A	2018	Long-term monitoring of the endemic *Rana latastei*: suggestions for after-LIFE management	Canal	Conservation concern	Italy	EURO		
Gavioli, A et al	2018	Managing the environment in a pinch: red swamp crayfish tells a cautionary tale of ecosystem based management in northeastern Italy	Canal	Alien	Italy	EURO		
Illyova, M & Cejka, T	2018	Crustacean Zooplankton Biodiversity in Agricultural Drainage Ditches in Danubian Lowland, Slovakia	Both	Alien/native	Slovakiaia	EURO		
Yamanaka, H et al	2018	Species-specific detection of the endangered piscivorous cyprinid fish *Opsariichthys uncirostris* uncirostris, three-lips, using environmental DNA analysis	Ditch	Conservation concern	Japan	JP		
Pitcher, KA & Yee, DA	2018	THE PREDACEOUS DIVING BEETLE FAUNA (COLEOPTERA: DYTISCIDAE) IN HIGHWAY-ASSOCIATED AQUATIC HABITATS IN SOUTHERN MISSISSIPPI, USA	Ditch	Native	US	NAm		
Clifford, CC & Heffernan, JB	2018	Artificial Aquatic Ecosystems	Both	All	Global	Global		
van Rees, CB et al	2018	Landscape genetics identifies streams and drainage infrastructure as dispersal corridors for an endangered wetland bird	Both	Conservation concern	US	NAm		
Teurlincx, S et al	2018	Managing Successional Stage Heterogeneity to Maximize Landscape-Wide Biodiversity of Aquatic Vegetation in Ditch Networks	Ditch	Native	Netherlands	EURO		
Bubikova, K & Hrivnak, R	2018	Comparative Macrophyte Diversity of Waterbodies in the Central European landscape	Both	Native	Slovakiaia	EURO		
Ljustina, O & Barrett, S	2018	Using Canals in Southern Florida to Measure Impacts of Urbanization on Herpetofaunal Community Composition	Canal	Alien/native	US	NAm		
Klassen, JA & Gawlik, DE	2018	Does a long-term shift in Wood Stork diet foreshadow adaptability to human-induced rapid environmental change?	Canal	Alien/native	US	NAm		
Hooley-Underwood, Z et al	2018	Combining Genetic, Isotopic, and Field Data to Better Describe the Influence of Dams and Diversions on Burbot Movement in the Wind River Drainage, Wyoming	Canal	Native	US	NAm		
Yigezu, G et al	2018	Habitat suitability modelling for predicting potential habitats of freshwater snail intermediate hosts in Omo-Gibe river basin, Southwest Ethiopia	Canal	Native	Ethiopia	EAf		
Hoffman, JR et al	2018	Genetic evidence for canal-mediated dispersal of Mapleleaf, *Quadrula quadrula* (Bivalvia: Unionidae) on the Niagara Peninsula, Canada	Canal	Native	Canada	NAm		
Bobori, DC et al	2018	Macroinvertebrate and fish communities in the watershed of a re-constructed Mediterranean water body: link to the ecological potential	Ditch	Alien/native	Greece	EURO		
Sundar, KSG et al	2018	The Role of Artificial Habitats and Rainfall Patterns in the Unseasonal Nesting of Sarus Cranes (Antigone antigone) in South Asia	Canal	Native	India	SAs		
Urbanska, M et al	2018	The invasive Asian clam Corbicula fluminea in Polish rivers: the importance of thermal discharge from power plants for its spread	Canal	Alien	Poland	EURO		
Radigan, WJ et al	2018	Otolith chemistry as a fisheries management tool after flooding: The case of Missouri River gizzard shad	Canal	Native	US	NAm		

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Villemey, A et al	2018	Can linear transportation infrastructure verges constitute a habitat and/or a corridor for insects in temperate landscapes? A systematic review	Both	All	Global	Global		
Rudi, G et al	2018	Using geomorphological variables to predict the spatial distribution of plant species in agricultural drainage networks	Ditch	Native	France	EURO		
Biaggini, M et al	2018	Breeding activity of the agile frog *Rana dalmatina* in a rural area	Ditch	Native	Italy	EURO		
Zhao, K et al	2018	Factors determining zooplankton assemblage difference among a man-made lake, connecting canals, and the water-origin river	Canal	Native	China	EAs		
Manfrin, C et al	2018	The Apparently Relentless Spread of the Major Decapod Alien Species in the Mediterranean Basin and European Inland Waters	Canal	Alien	Europe	EURO		
Rolke, D et al	2018	Drainage ditches as important habitat for species diversity and rare species of aquatic beetles in agricultural landscapes (Insecta: Coleoptera)	Ditch	Conservation concern	Germany	EURO		
Rasran, L & Vogt, K	2018	Ditches as species-rich secondary habitats and refuge for meadow species in agricultural marsh grasslands	Ditch	Native	Germany	EURO		
Vignoles, P et al	2018	Consequences of invasion by *Pseudosuccinea columella* on the dynamics of native lymnaeids living on the acid soils of central France	Ditch	Alien/native	France	EURO		
Al-Amro, AM et al	2018	VEGETATION ANALYSIS OF SOME WETLAND HABITATS IN CENTRAL REGION OF SAUDI ARABIA	Canal	Native	Saudi Arabia	MEa		
Pieper, SJ et al	2018	Coexistence of *Typha latifolia*, T-angustifolia (Typhaceae) and their invasive hybrid is not explained by niche partitioning across water depths	Ditch	Alien/native	Canada	NAm		
Golubovic, A et al	2017	Actual and Potential Distribution of the European Pond Turtle, *Emys orbicularis* (L., 1758) in Serbia, with Conservation Implications	Canal	Conservation concern	Serbia	EURO		
Marsden, JE & Ladago, BJ	2017	The Champlain Canal as a non-indigenous species corridor	Canal	Alien/native	US	NAm		
Pereira, JL et al	2017	Invasive Asian clam distribution pattern reveals minimal constraints to downstream dispersal and imperceptible ecological impacts	Ditch	Alien	Portugal	EURO		
Ward-Campbell, B et al	2017	Fish assemblages in agricultural drains are resilient to habitat change caused by drain maintenance	Ditch	All	Canada	NAm		
Sehr, M & Keckeis, H	2017	Habitat use of the European mudminnow *Umbra krameri* and association with other fish species in a disconnected Danube side arm	Ditch	Conservation concern	Austria	EURO		
Strecker, AL & Brittain, JT	2017	Increased habitat connectivity homogenizes freshwater communities: historical and landscape perspectives	Canal	Alien/native	US	NAm		
Docherty, C et al	2017	Assessing the spread and potential impact of Prussian Carp *Carassius gibelio* (Bloch, 1782) to freshwater fishes in western North America	Canal	Alien	Canada	NAm		
Pierre, SM et al	2017	Dispersal and local environment affect the spread of an invasive apple snail (Pomacea maculata) in Florida, USA	Both	Alien	US	NAm		
Koizumi, N et al	2017	Plant species identification using fecal DNAs from red-eared slider and Reeves' pond turtle in agricultural canals for rural ecosystem conservation	Canal	Alien/native	Japan	JP		
Meier, M et al	2017	Plant diversity in a water-meadow landscape: the role of irrigation ditches	Ditch	Native	Germany	EURO		
Rountree, RA & Juanes, F	2017	Potential of passive acoustic recording for monitoring invasive species: freshwater drum invasion of the Hudson River via the New York canal system	Canal	Alien	US	NAm		
Bisping, SM & Thompson, BC	2017	Importance of Canals for Florida Largemouth Bass: Lake Griffin, Florida	Canal	Native	US	NAm		
Czerniawski, R & Slugocki, L	2017	Analysis of zooplankton assemblages from man-made ditches in relation to current velocity	Ditch	Native	Poland	EURO		
Biggs, J et al	2017	The importance of small waterbodies for biodiversity and ecosystem services: implications for policy makers	Ditch	All	Global	Global		
Vinarski, MV et al	2017	The history of an invasion: phases of the explosive spread of the physid snail *Physella acuta* through Europe, Transcaucasia and Central Asia	Canal	Alien	Europe, Transcaucasia, and Central Asia	EURO, CAs		

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Kulkoyluoglu, O et al	2017	Comparison of Ostracoda (Crustacea) species diversity, distribution and ecological characteristics among habitat types	Canal	Native	Turkey	MEa		
Pittfield, T & Burger, J	2017	Basking habitat use and response of freshwater turtles to human presence in an urban canal of Central New Jersey	Canal	Alien/native	US	NAm		
Jacobs, AI & Keller, RP	2017	Straddling the divide: invasive aquatic species in Illinois and movement between the Great Lakes and Mississippi basins	Canal	Alien	US	NAm		
Weber, A & Wolter, C	2017	Habitat rehabilitation for juvenile fish in urban waterways: A case study from Berlin, Germany	Canal	Native	Germany	EURO		
Leslie, AW & Lamp, WO	2017	Taxonomic and functional group composition of macroinvertebrate assemblages in agricultural drainage ditches	Ditch	Native	US	NAm		
Gandy, DA & Rehage, JS	2017	Examining gradients in ecosystem novelty: fish assemblage structure in an invaded Everglades canal system	Canal	Alien/native	US	NAm		
Vamberger, M et al	2017	Distribution and population size of the European pond turtle Emys orbicularis in Ljubljansko barje, Slovenia	Ditch	Conservation concern	Slovenia	EURO		
Arbaciauskas, K et al	2017	Range expansion of Ponto-Caspian peracaridan Crustaceans in the Baltic Sea basin and its aftermath: Lessons from Lithuania	Canal	Alien	Lithuania	EURO		
Prie, V & Fruget, JF	2017	Heading south: new records of the invasive quagga mussel Dreissena rostriformis bugensis (Andrusov, 1897) in France and further perspectives	Canal	Alien	France	EURO		
Weiss, A & Arndt, C	2017	The potential of nearly natural mill ditches as an independent biotope-type	Ditch	Native	Germany	EURO		
Zielinska, KM et al	2017	VASCULAR PLANTS AND BRYOPHYTES IN MANAGED FORESTS - ANALYSIS OF THE IMPACT OF THE OLD DITCHES ON THE SPECIES DIVERSITY (CENTRAL EUROPEAN PLAIN)	Ditch	Native	Poland	EURO		
Goodman, DH et al	2017	Screen Efficiency and Implications for Losses of Lamprey Macrophthalmia at California's Largest Water Diversions	Canal	Native	US	NAm		
Davis, AM & Moore, AR	2016	Conservation potential of artificial water bodies for fish communities on a heavily modified agricultural floodplain	Ditch	Alien/native	Australia	OZ		
Kim, J & Mandrak, NE	2016	Assessing the potential movement of invasive fishes through the Welland Canal	Canal	Alien/native	Canada-US	NAm		
Andelkovic, AA et al	2016	The contemporary records of aquatic plants invasion through the Danubian floodplain corridor in Serbia	Canal	Alien	Serbia	EURO		
Aspe, C et al	2016	Irrigation canals as tools for climate change adaptation and fish biodiversity management in Southern France	Canal	Alien/native	France	EURO		
Rhoden, CM et al	2016	Highway to heaven? Roadsides as preferred habitat for two narrowly endemic crayfish	Ditch	Conservation concern	US	NAm		
Rakauskas, V et al	2016	Non-indigenous fish in the northern branch of the central European invasion corridor	Canal	Alien	Lithuania	EURO		
Wiatrowska, B & Danielewicz, W	2016	Environmental determinants of the steeplebush (*Spiraea tomentosa* L.) invasion in the Bory Dolnoslaskie Forest	Ditch	Alien	Poland	EURO		
Staniaszek-Kik, M et al	2016	How do ditches contribute to bryophyte diversity in managed forests in East-Central Europe?	Ditch	Conservation concern	Poland	EURO		
Stevens, PW et al	2016	Resilience of a tropical sport fish population to a severe cold event varies across five estuaries in southern Florida	Canal	Native	US	NAm		
Hill, MJ et al	2016	Aquatic macroinvertebrate biodiversity associated with artificial agricultural drainage ditches	Ditch	Alien/native	UK	BI		
Leite, MGP et al	2016	Irrigation canals in Melo creek basin (Rio Espera and Capela Nova municipalities, Minas Gerais, Brazil): habitats to Biomphalaria (Gastropoda: Planorbidae) and potential spread of schistosomiasis	Canal	Native	Brazil	SAm		
Ishiyama, N et al	2016	Biodiversity and rarity distributions of native freshwater fish in an agricultural landscape: the importance of beta diversity between and within water-body types	Ditch	Native	Japan	JP		

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Appendix Table A1 (*continued*)

Author	Year	Title	Structure	Species/community	Location	Location 2	Row labels	Count of structure
Son, MO et al	2020	Caspian invaders vs. Ponto-Caspian locals - range expansion of invasive macroinvertebrates from the Volga Basin results in high biological pollution of the Lower Don River	Canal	Alien	Ponto-Caspian region	EURO	both	30
Johnson, BA et al	2016	Anuran occupancy and breeding site use of aquatic systems in a managed pine landscape	Ditch	Native	US	NAm		
Balazi, P & Hrivnak, R	2016	The relationship between macrophyte assemblages and environmental variables in drainage and irrigation canals in Slovakia.	Canal	Native	Slovakiaia	EURO		
Dzigurski, D et al	2016	Vegetation of the Hydrochari-Lemnete and Potametea classes in the Danube-Tisza-Danube hydrosystem (Serbia)	Canal	Conservation concern	Serbia	EURO		
Rochford, MR et al	2016	MOLECULAR ANALYSES CONFIRMING THE INTRODUCTION OF NILE CROCODILES, *CROCODYLUS NILOTICUS* LAURENTI 1768 (CROCODYLIDAE), IN SOUTHERN FLORIDA, WITH AN ASSESSMENT OF POTENTIAL FOR ESTABLISHMENT, SPREAD, AND IMPACTS	Canal	Alien	US	NAm		
Elston, J et al	2016	URBAN DITCH CHARACTERISTICS ASSOCIATED WITH TURTLE ABUNDANCE AND SPECIES RICHNESS	Canal	Native	US	NAm		
O'Bryan, CJ et al	2016	Novel habitat use supports population maintenance in a reconfigured landscape	Ditch	Conservation concern	US	NAm		
Homyack, JA et al	2016	Community occupancy of herpetofauna in roadside ditches in a managed pine landscape	Ditch	Native	US	NAm		
Favre-Bac, L et al	2016	Ditch network sustains functional connectivity and influences patterns of gene flow in an intensive agricultural landscape	Ditch	Native	France	EURO		
Katagiri, K et al	2016	THE IMPORTANCE OF CONSOLIDATED DRAINAGE CANALS AS A HABITAT FOR AQUATIC PLANTS	Canal	Native	Japan	JP		
Vitale, D et al	2016	“Opisthobranch” (molluscs) inventory of the Faro Lake: a Sicilian biodiversity hot spot	Canal	Alien/native	Italy	EURO		
Bakonyi, G et al.	2016	SOME MORPHOLOGICAL CHARACTERISTICS OF THE WATER SCORPION *NEPA CINEREA* (HETEROPTERA: NEPOMORPHA) ARE ASSOCIATED WITH HABITAT TYPE	Canal	Native	Hungary	EURO		
Galal, TM & Shehata, HS	2016	Growth and nutrients accumulation potentials of giant reed (*Arundo donax* L.) in different habitats in Egypt	Canal	Alien	Egypt	NAf		
Rostami, R et al	2016	Effect of landscape structure on agrobiodiversity in western Iran (Gilan-E Gharb)	Ditch	Native	Iran	MEa		
Svoboda, AD et al	2016	Status and Distribution of the Least Darter (*Etheostoma microperca* Jordan and Gilbert) in Ohio: A State Listed Species of Concern	Ditch	Conservation concern	US	NAm		
Marescaux, J et al	2016	Unravelling the invasion pathways of the quagga mussel (Dreissena rostriformis) into Western Europe	Canal	Alien	Europe	EURO		
Rahman, MKM et al	2016	MICROHABITAT ECOLOGY OF SEMI-AQUATIC *VARANUS FLAVESCENS* (REPTILIA: VARANIDAE) IN ALTERED HABITATS	Canal	Native	Bangladesh	SAs		
Hulme, PE	2015	Invasion pathways at a crossroad: policy and research challenges for managing alien species introductions	Canal	Alien	Global	Global		
Wen, A	2015	Association Between Habitat Characteristics, Human Activities, and Anuran Species in a Wetland Agricultural Landscape	Ditch	Native	US	NAm		
Braulik, GT et al	2015	Review of status, threats, and conservation management options for the endangered Indus River blind dolphin	Canal	Conservation concern	Pakistan	SAs		
Wu, P et al	2015	Effects of drainage water on plant diversity and distribution of agricultural drainage ditch beds in an arid irrigated area of Northwestern China	Ditch	Native	China	EAs		
Vaikre, M et al	2015	Macroinvertebrates in woodland pools and ditches and their response to artificial drainage in Estonia	Ditch	Native	Estonia	EURO		
Zhan, AB et al	2015	Water diversions facilitate spread of non-native species	Canal	Alien	China	EAs		
Verma, S & Khan, JB	2015	STUDY ON AQUATIC PLANT BIODIVERSITY IN SHIV GANGA CANAL, BITS PILANI IN JHUNJHUNU (RAJ.) INDIA	Canal	Native	India	SAs		
Nunes, AL et al	2015	Pathways and gateways of freshwater invasions in Europe	Canal	Alien	Europe	EURO		
Shaw, RF et al	2015	Enhancing the Biodiversity of Ditches in Intensively Managed UK Farmland	Ditch	Alien/native	UK	BI		

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Remm, L et al	2015	Temporary and small waterbodies in human-impacted forests: an assessment in Estonia	Ditch	Native	Estonia	EURO		
Pedreschi, D et al	2015	Trophic flexibility and opportunism in pike *Esox lucius*	Canal	Alien	Ireland	BI		
Tichanek, F & Tropek, R	2015	Conservation value of post-mining headwaters: drainage channels at a lignite spoil heap harbour threatened stream dragonflies	Ditch	Conservation concern	Czech	EURO		
Waddle, JH et al	2015	Dry Years Decrease Abundance of American Alligators in the Florida Everglades	Canal	Native	US	NAm		
Smith, C et al	2015	Pomacea maculata (Island Apple Snail) Invasion in Seasonal Wetlands on Florida Ranchland: Association with Plant-Community Structure and Aquatic-Predator Abundance	Both	Alien	US	NAm		
Oele, DL et al	2015	Chemical tracking of northern pike migrations: If we restore access to breeding habitat, will they come?	Ditch	Native	US	NAm		
Nakano, M et al	2015	Unionid Freshwater Mussels in Irrigation Ditches Are Affected by Physical Environmental Factors and Proximity to Paddy Fields	Ditch	Native	Japan	JP		
Munoz-Ramirez, CP et al	2015	Inter-basin dispersal through irrigation canals explains low genetic structure in *Diplomystes* cf. *chilensis*, an endangered freshwater catfish from Central Chile	Canal	Conservation concern	Chile	SAm		
Korres, NE et al	2015	Distribution of Arable Weed Populations along Eastern Arkansas Mississippi Delta Roadsides: Occurrence, Distribution, and Favored Growth Habitats	Ditch	Native	US	NAm		
Marescaux, J et al	2015	Sympatric Dreissena species in the Meuse River: towards a dominance shift from zebra to quagga mussels	Canal	Alien/native	Belgium	EURO		
Ohira, M et al	2015	Niche processes and conservation implications of fish community assembly in a rice irrigation system	Both	Native	Japan	JP		
Whatley, MH et al	2015	Temporal abiotic variability structures invertebrate communities in agricultural drainage ditches	Ditch	Native	Netherlands	EURO		
Clarke, SJ	2015	Conserving freshwater biodiversity: The value, status and management of high quality ditch systems	Ditch	All	UK	BI		
Valdesalici, S et al	2015	Distribution of natural populations of the killifish *Aphanius fasciatus* (Valenciennes, 1821) (Teleostei: Cyprinodontidae) in Italy: past and current status, and future trends	Canal	Conservation concern	Italy	EURO		
Harabis, F & Dolny, A	2015	Necessity for the conservation of drainage systems as last refugia for threatened damselfly species, Coenagrion ornatum	Ditch	Conservation concern	Czech	EURO		
Moser, ML et al	2015	Behaviour and potential threats to survival of migrating lamprey ammocoetes and macrophthalmia	Canal	Conservation concern	Global	Global		
Agdamar, S et al	2015	The role of environmental factors and genetic diversity on colonization success of a non-native fish, *Lepomis gibbosus* from western part of Turkey	Canal	Alien	Turkey	MEa		
Eggers, F et al	2015	Individual habitat transitions of Atlantic herring *Clupea harengus* in a human-modified coastal system	Canal	Native	Norway	EURO		
Cudowski, A et al	2015	Aquatic fungi in relation to the physical and chemical parameters of water quality in the Augustow Canal	Canal	Native	Poland–Belarus	EURO		
Miller, BA et al	2015	Diet Partitioning in a Diverse Centrarchid Assemblage in the Atchafalaya River Basin, Louisiana	Canal	Native	US	NAm		
Onikura, N et al	2015	Site selection for habitat conservation/restoration of threatened freshwater fishes in artificial channels of northern Kyushu Island, Japan	Both	All	Japan	JP		
Nishida, K et al	2015	Influence of the domestic alien fish Rhynchocypris oxycephalus invasion on the distribution of the closely related native fish R-lagowskii in the Tama River Basin, Japan	Canal	Alien/native	Japan	JP		
Hara, A et al	2015	Canal type affects invasiveness of the apple snail *Pomacea canaliculata* through its effects on animal species richness and waterweed invasion	Canal	Alien/native	Japan	JP		

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Misra, A et al	2015	Assessment of the land use/land cover (LU/LC) and mangrove changes along the Mandovi-Zuari estuarine complex of Goa, India	Canal	Native	India	SAs		
Papastamatiou, YP et-al	2015	A subtropical embayment serves as essential habitat for sub-adults and adults of the critically endangered smalltooth sawfish	Canal	Conservation concern	US	NAm		
Homyack, JA et al	2015	Anuran assemblages associated with roadside ditches in a managed pine landscape	Ditch	Native	US	NAm		
Harvolk, S et al.	2014	Can artificial waterways provide a refuge for floodplain biodiversity? A case study from North Western Germany	Canal	Conservation concern	Germany	EURO		
Mazzini, I et al	2014	Ostracod communities associated to aquatic macrophytes in an urban park in Rome, Italy	Ditch	Alien/native	Italy	EURO		
Kurita, Y et al	2014	Factors affecting the establishment success of the invasive piscivorous chub in small irrigation ditches in northern Kyushu, Japan	Ditch	Alien	Japan	JP		
Brown, ME et al	2014	Fifteen miles on the Erie Canal: the spread of *Hemimysis anomala* GO Sars, 1907 (bloody red shrimp) in the New York State canal system	Canal	Alien	US	NAm		
Sherwood, AR et al	2014	The Hawaiian freshwater algae biodiversity survey (2009–2014): systematic and biogeographic trends with an emphasis on the macroalgae	Ditch	Native	US	NAm		
Sayer, CD	2014	Conservation of aquatic landscapes: ponds, lakes, and rivers as integrated systems	Ditch	Native	UK	BI		
Paradis, E et al	2014	Interspecific Competition for Space Between Wetland Plants with Clonal Growth	Ditch	Alien/native	Canada	NAm		
Bouetard, A et al	2014	Environmental versus Anthropogenic Effects on Population Adaptive Divergence in the Freshwater Snail *Lymnaea stagnalis*	Ditch	Native	Europe	EURO		
Parkos, JJ & Trexler, JC	2014	Origins of functional connectivity in a human-modified wetland landscape	Canal	Alien/native	US	NAm		
Whatley, MH et al	2014	The role of emergent vegetation in structuring aquatic insect communities in peatland drainage ditches	Ditch	Native	Netherlands	EURO		
Bernatis, JL & Warren, GL	2014	Effectiveness of a Hand Removal Program for Management of Nonindigenous Apple Snails in an Urban Pond	Both	Alien	US	NAm		
Negishi, JN et al	2014	Imperiled freshwater mussels in drainage channels associated with rare agricultural landscape and diverse fish communities	Ditch	Native	Japan	JP		
Zeug, SC & Cavallo, BJ	2014	Controls on the Entrainment of Juvenile Chinook Salmon (Oncorhynchus tshawytscha) into Large Water Diversions and Estimates of Population-Level Loss	Canal	Native	US	NAm		
Ishiyama, N et al	2014	Mobility-dependent response of aquatic animal species richness to a wetland network in an agricultural landscape	Canal	Native	Japan	JP		
Nishida, K et al	2014	Movement and assemblage of fish in an artificial wetland and canal in a paddy fields area, in eastern Japan	Canal	Native	Japan	JP		
D'Ambrosio, JL et al	2014	Geomorphology, habitat, and spatial location influences on fish and macroinvertebrate communities in modified channels of an agriculturally-dominated watershed in Ohio, USA	Ditch	Native	US	NAm		
Dibner, RR et al	2014	REPRODUCTION OF COMMON FROGS, *RANA TEMPORARIA*, IN A MANAGED CONIFER FOREST AND BOG LANDSCAPE IN WESTERN IRELAND	Ditch	Conservation concern	Ireland	BI		
Krebs, JM et al	2014	Nekton Community Structure Varies in Response to Coastal Urbanization Near Mangrove Tidal Tributaries	Ditch	Alien/native	US	NAm		
Kalcheva, H et al	2014	Bacterioplankton of Wetlands along the Lower Danube River (Bulgaria) and Its Relation to Environmental Factors	Canal	Native	Bulgaria	EURO		
Meineri, E et al	2014	Distribution and reproduction of Procambarus clarkii in relation to water management, salinity and habitat type in the Camargue	Canal	Alien	France	EURO		
Ryan, TJ et al	2014	Movement and habitat use of the snapping turtle in an urban landscape	Canal	Native	US	NAm		

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Kline, JL et al	2014	Recent Fish Introductions Into Everglades National Park: An Unforeseen Consequence of Water Management?	Canal	Alien	US	NAm		
Eshenroder, RL	2014	The Role of the Champlain Canal and Erie Canal as Putative Corridors for Colonization of Lake Champlain and Lake Ontario by Sea Lampreys	Canal	Alien	US	NAm		
Kwan, YS et al	2014	Genomic replacement of native *Cobitis lutheri* with introduced *C. tetralineata* through a hybrid swarm following the artificial connection of river systems	Canal	Alien/native	Korea	EAs		
Halstead, BJ et al	2014	Ghost of habitat past: historic habitat affects the contemporary distribution of giant garter snakes in a modified landscape	Canal	Conservation concern	US	NAm		
Pekarik, L et al	2014	Identifying the key habitat characteristics of threatened European mudminnow (Umbra krameri, Walbaum 1792)	Canal	Conservation concern	Slovakiaia	EURO		
van Dijk, WFA et al	2014	The effectiveness of ditch banks as dispersal corridor for plants in agricultural landscapes depends on species' dispersal traits	Ditch	Native	Netherlands	EURO		
Rosenvald, R et al	2014	Fish assemblages in forest drainage ditches: Degraded small streams or novel habitats?	Ditch	Alien/native	Estonia	EURO		
Garcia, ME & Aboal, M	2014	Environmental gradients and macroalgae in Mediterranean marshes: the case of Pego-Oliva marsh (East Iberian Peninsula)	Ditch	Native	Spain	EURO		
Vincent, RE et al	2014	Ditching and Ditch-Plugging in New England Salt Marshes: Effects on Plant Communities and Self-Maintenance	Ditch	Native	US	NAm		
Reid, N et al	2014	Assessing Historical and Current Threats to Common Frog (Rana temporaria) Populations in Ireland	Ditch	Conservation concern	Ireland	BI		
Nowak, A et al	2014	DIVERSITY AND DISTRIBUTION OF RUSH COMMUNITIES FROM THE PHRAGMITO-MAGNO-CARICETEA CLASS IN PAMIR ALAI MOUNTAINS (MIDDLE ASIA: TAJIKISTAN)	Ditch	Alien/native	Tajikistan	CAs		
Tang, Q et al	2014	Effects of corridor networks on plant species composition and diversity in an intensive agriculture landscape	Ditch	Native	China	EAs		
Hrivnak, R et al	2014	Environmental drivers of macrophyte species richness in artificial and natural aquatic water bodies - comparative approach from two central European regions	Canal	Alien/native	Slovakiaia	EURO		
Liu, B et al	2014	Community structure of ammonia-oxidizing microorganisms in the Grand Canal, Zhenjiang, of Jiangsu Province, China	Canal	Native	China	EAs		
Blakely, TJ et al	2014	The Singscore: a macroinvertebrate biotic index for assessing the health of Singapore's streams and canals	Canal	Native	Singapore	SEA		
Marlor, KM et al	2014	Disturbance and Wetland Type Alter Reed Canarygrass Cover in Northern Michigan	Ditch	Alien/native	US	NAm		
Whatley, MH et al	2014	Macrophyte loss drives decadal change in benthic invertebrates in peatland drainage ditches	Ditch	Native	Netherlands	EURO		
Shinohara, R et al	2014	Effects of phytoplankton on the distribution of submerged macrophytes in a small canal	Canal	Native	Japan	JP		
Matthews, J et al	2014	Rapid range expansion of the invasive quagga mussel in relation to zebra mussel presence in The Netherlands and Western Europe	Canal	Alien	Europe	EURO		
Hanafiah, MM et al.	2013	Including the Introduction of Exotic Species in Life Cycle Impact Assessment: The Case of Inland Shipping	Canal	Alien	Europe	EURO		
Endo, C & Nagata, H	2013	Seasonal changes of foraging habitats and prey species in the Japanese Crested Ibis *Nipponia nippon* reintroduced on Sado Island, Japan	Ditch	Conservation concern	Japan	JP		
Kloskowski, J et al	2013	Resource availability and use by Eurasian otters *Lutra lutra* in a heavily modified river-canal system	Canal	Conservation concern	Poland	EURO		
Rothlisberger, JD & Lodge, DM	2013	The Laurentian Great Lakes as a beachhead and a gathering place for biological invasions	Canal	Alien	Canada-US	NAm		

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Fukuda, S et al	2013	Modelling the distribution of the pan-continental invasive fish *Pseudorasbora parva* based on landscape features in the northern Kyushu Island, Japan	Canal	Alien	Japan	JP		
Waltham, NJ & Connolly, RM	2013	Artificial tidal lakes: Built for humans, home for fish	Canal	Native	Australia	OZ		
Reid, N et al	2013	Population enumeration and assessing conservation status in a widespread amphibian: a case study of Rana temporaria in Ireland	Ditch	Conservation concern	Ireland	BI		
Shah, V et al	2013	Taxonomic Profiling and Metagenome Analysis of a Microbial Community from a Habitat Contaminated with Industrial Discharges	Canal	Native	India	SAs		
Walsh, GC et al	2013	Persistence of floating pennyvvort patches (*Hydrocotyle ranunculoides*, Araliaceae) in a canal in its native temperate range: Effect of its. Natural enemies	Canal	Native	Argentina	SAm		
Chester, ET & Robson, BJ	2013	Anthropogenic refuges for freshwater biodiversity: Their ecological characteristics and management	Both	All	Global	Global		
Boets, P et al	2013	Data-driven habitat analysis of the Ponto-Caspian amphipod Dikerogammarus villosus in two invaded regions in Europe	Canal	Alien	Belgium and Croatia	EURO		
Ferreira, M & Beja, P	2013	Mediterranean amphibians and the loss of temporary ponds: Are there alternative breeding habitats?	Ditch	Native	Portugal	EURO		
Hayashi, K et al	2013	Growth and habitat use of the Chinese false gudgeon, *Abbottina rivularis*, in an irrigation channel near the Ushizu River, northern Kyushu Island, Japan	Ditch	Alien	Japan	JP		
Bogdan, HV et al	2013	Conservation implications on present distribution of herpetofauna from plain areas of the Western Banat region, Romania	Both	Conservation concern	Romania	EURO		
Luk, YC & Zajac, RN	2013	Spatial Ecology of Fiddler Crabs, *Uca pugnax*, in Southern New England Salt Marsh Landscapes: Potential Habitat Expansion in Relation to Salt Marsh Change	Ditch	Native	US	NAm		
Dorotovicova, C	2013	Man-made canals as a hotspot of aquatic macrophyte biodiversity in Slovakia	Canal	All	Slovakiaia	EURO		
van Dijk, WFA et al	2013	Temporal effects of agri-environment schemes on ditch bank plant species	Ditch	Native	Netherlands	EURO		
Castaldelli, G et al	2013	Introduction of exotic fish species and decline of native species in the lower Po basin, north-eastern Italy	Canal	All	Italy	EURO		
Li, DL et al	2013	The importance of artificial habitats to migratory waterbirds within a natural/artificial wetland mosaic, Yellow River Delta, China	Canal	Native	China	EAs		
Rahel, FJ	2013	Intentional Fragmentation as a Management Strategy in Aquatic Systems	Canal	All	Global	Global		
Poulakis, GR et al	2013	Movements of juvenile endangered smalltooth sawfish, *Pristis pectinata*, in an estuarine river system: use of non-main-stem river habitats and lagged responses to freshwater inflow-related changes	Canal	Conservation concern	US	NAm		
Lobos, G et al	2013	Invasive African clawed frog *Xenopus laevis* in southern South America: key factors and predictions	Canal	Alien	Chile	SAm		
Soomers, H et al	2013	Wind and Water Dispersal of Wetland Plants Across Fragmented Landscapes	Both	Native	Netherlands	EURO		
Solomon, LE et al	2013	Juvenile Alligator Gar Movement Patterns in a Disconnected Floodplain Habitat in Southeast Missouri	Ditch	Conservation concern	US	NAm		
Onikura, N & Nakajima, J	2013	Age, growth and habitat use of the topmouth gudgeon, Pseudorasbora parva in irrigation ditches on northwestern Kyushu Island, Japan	Ditch	Native	Japan	JP		
Zielinska, KM et al	2013	Influence of Ditches on Plant Species Diversity in the Managed Forests of Central Poland	Ditch	Native	Poland	EURO		
Athibai, S et al	2013	Diversity and distribution of Brachionidae (Rotifera) in Thailand, with a key to the species	Canal	Native	Thailand	SEA		
Gioria, M & Osborne, BA	2013	Biological Flora of the British Isles: *Gunnera tinctoria*	Ditch	Alien	UK and Ireland	BI		

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van Zuidam, JP & Peeters, ETHM	2013	Occurrence of macrophyte monocultures in drainage ditches relates to phosphorus in both sediment and water	Ditch	Native	Netherlands	EURO		
Lebeda, A et al	2012	Wild and weedy Lactuca species, their distribution, ecogeography and ecobiology in USA and Canada	Ditch	Alien/native	Canada-US	NAm		
Werry, JM et al	2012	Natural or Artificial? Habitat-Use by the Bull Shark, *Carcharhinus leucas*	Canal	Native	Australia	OZ		
Mikulicek, P & Pisut, P	2012	Genetic structure of the marsh frog (*Pelophylax ridibundus*) populations in urban landscape	Canal	Native	Slovakia	EURO		
Naito, R et al	2012	Negative Effects of Deep Roadside Ditches on Pelophylax porosa brevipoda Dispersal and Migration in Comparison with *Hyla japonica* in a Rice Paddy Area in Japan	Ditch	Conservation concern	Japan	JP		
Leslie, AW et al	2012	Environmental Factors Structuring Benthic Macroinvertebrate Communities of Agricultural Ditches in Maryland	Ditch	Native	US	NAm		
Gandy, DA et al	2012	Canals as Vectors for Fish Movement: Potential Southward Range Expansion of *Lepisosteus osseus* L. (Longnose Gar) in South Florida	Canal	Native	US	NAm		
Cammaerts, R et al	2012	Colonization of the Border Meuse area (The Netherlands and Belgium) by the non-native western tubenose goby Proterorhinus semilunaris (Heckel, 1837) (Teleostei, Gobiidae)	Canal	Alien	Netherlands and Belgium	EURO		
Wells, EF	2012	Reintroduction of Federally Endangered Harperella (Harperella nodosum Rose) in Flood-Prone, Artificial, and Natural Habitats	Canal	Conservation concern	US	NAm		
Shi, XL et al	2012	An approach to analyzing spatial patterns of protozoan communities for assessing water quality in the Hangzhou section of Jing-Hang Grand Canal in China	Canal	Native	China	EAs		
Zalewska-Galosz, J et al	2012	Ecological variation between marginal and central populations of *Potamogeton polygonifolius*, a rare and endangered species in Central Europe	Ditch	Conservation concern	Poland	EURO		
Shi, XL et al	2012	Application of phytoplankton communities for monitoring water quality in the Hangzhou section of Jing-Hang Grand Canal, southern China	Canal	Native	china	EAs		
Verdonschot, RCM et al	2012	Development of a multimetric index based on macroinvertebrates for drainage ditch networks in agricultural areas	Ditch	All	Netherlands	EURO		
Bodis, E et al	2012	INVASIVE MOLLUSC, CRUSTACEAN, FISH AND REPTILE SPECIES ALONG THE HUNGARIAN STRETCH OF THE RIVER DANUBE AND SOME CONNECTED WATERS	Canal	Alien	Hungary	EURO		
Walters, AW et al	2012	Quantifying Cumulative Entrainment Effects for Chinook Salmon in a Heavily Irrigated Watershed	Canal	Conservation concern	US	NAm		
Ellis, A et al	2012	Present distribution and future spread of louisiana red swamp crayfish Procambarus clarkii (Crustacea, Decapoda, Astacida, Cambaridae) in Britain: Implications for conservation of native species and habitats	Canal	Alien	UK	BI		
Simpson, WG & Ostrand, KG	2012	Effects of Entrainment and Bypass at Screened Irrigation Canals on Juvenile Steelhead	Canal	Native	US	NAm		
Panfili, J et al	2012	Habitat residence during continental life of the European eel Anguilla anguilla investigated using linear discriminant analysis applied to otolith Sr:Ca ratios	Canal	Conservation concern	France	EURO		
Abeli, T et al	2012	A cost-effective model for preliminary site evaluation for the reintroduction of a threatened quillwort	Canal	Conservation concern	Italy	EURO		
Turic, N et al	2012	Structure of aquatic assemblages of Coleoptera and Heteroptera in relation to habitat type and flood dynamic structure	Canal	Native	Croatia	EURO		
Ohba, SY et al	2011	MOSQUITOES AND THEIR POTENTIAL PREDATORS IN RICE AGROECOSYSTEMS OF THE MEKONG DELTA, SOUTHERN VIETNAM	Both	Native	Vietnam	SEA		
Vermonden, K et al	2011	The influence of environmental factors and dredging on chironomid larval diversity in urban drainage systems in polders strongly influenced by seepage from large rivers	Ditch	Native	Netherlands	EURO		

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Appendix Table A1 (*continued*)

Author	Year	Title	Structure	Species/community	Location	Location 2	Row labels	Count of structure
Son, MO et al	2020	Caspian invaders vs. Ponto-Caspian locals - range expansion of invasive macroinvertebrates from the Volga Basin results in high biological pollution of the Lower Don River	Canal	Alien	Ponto-Caspian region	EURO	both	30
Maltchik, L et al	2011	Can rice field channels contribute to biodiversity conservation in Southern Brazilian wetlands?	Both	Native	Brazil	SAm		
Verdonschot, RCM et-al	2011	Biodiversity value of agricultural drainage ditches: a comparative analysis of the aquatic invertebrate fauna of ditches and small lakes	Ditch	Native	Netherlands	EURO		
Hartel, T et al	2011	Spatial and temporal variability of aquatic habitat use by amphibians in a hydrologically modified landscape	Ditch	Native	Romania	EURO		
Sun, QX et al	2011	Response of Oncomelania snail distribution on land use in Sichuan, China	Ditch	Native	China	EAs		
Zhang, YC et al	2011	Vegetation responses to integrated water management in the Ejina basin, northwest China	Canal	Native	China	EAs		
Suislepp, K et al	2011	Impacts of artificial drainage on amphibian breeding sites in hemiboreal forests	Ditch	Native	Estonia	EURO		
Terui, A et al	2011	Factors affecting the local occurrence of the near-threatened bitterling (*Tanakia lanceolata*) in agricultural canal networks: strong attachment to its potential host mussels	Both	Conservation concern	Japan	JP		
Kerfoot, JR et al	2011	Environmental correlates of the abundance and distribution of *Belonesox belizanus* in a novel environment	Canal	Alien	US	NAm		
Bevacqua, D et al	2011	Density-dependent and inter-specific interactions affecting European eel settlement in freshwater habitats	Canal	Conservation concern	France	EURO		
Matsuzaki, SS et al	2011	Influence of connectivity, habitat quality and invasive species on egg and larval distributions and local abundance of crucian carp in Japanese agricultural landscapes	Ditch	Alien	Japan	JP		
Eubanks, BW et al	2011	Habitat associations of the marsh rice rat (*Oryzomys palustris*) in freshwater wetlands of southern Illinois	Ditch	Native	US	NAm		
Richards, TM et al	2011	Microhabitat associations of a semi-terrestrial fish, Kryptolebias marmoratus (Poey 1880) in a mosquito-ditched mangrove forest, west-central Florida	Ditch	Native	US	NAm		
Cherkiss, MS et al	2011	The American Crocodile in Biscayne Bay, Florida	Canal	Conservation concern	US	NAm		
Chaichana, R et al	2011	Habitat, abundance and diet of invasive suckermouth armored catfish (Loricariidae Pterygoplichthys) in the Nong Yai Canal, East Thailand	Canal	Alien	Thailand	SEA		
Chaves-Campos, J et-al	2011	Phylogeography, genetic structure, and gene flow in the endemic freshwater shrimp Palaemonetes suttkusi from Cuatro Ci,negas, Mexico	Canal	Conservation concern	Mexico	CAm		
Jerde, CL et al	2011	"Sight-unseen" detection of rare aquatic species using environmental DNA	Canal	Alien	US	NAm		
Sanabria, E et al	2011	A new record for American Bullfrog (*Lithobates catesbeianus*) in San Juan, Argentina	Canal	Alien	Argentina	SAm		
Simon, TN & Travis, J	2011	The contribution of man-made ditches to the regional stream biodiversity of the new river watershed in the Florida panhandle	Ditch	Native	US	NAm		
Chucholl, C	2011	Disjunct distribution pattern of Procambarus clarkii (Crustacea, Decapoda, Astacida, Cambaridae) in an artificial lake system in Southwestern Germany	Canal	Alien	Germany	EURO		
Maier, G et al	2011	New records of the rare glacial relict *Eurytemora lacustris* (Poppe 1887) (Copepoda; Calanoida) in atypical lake habitats of northern Germany	Canal	Alien	Germany	EURO		
Corman, SS & Roman, CT	2011	Comparison of salt marsh creeks and ditches as habitat for nekton	Ditch	Native	US	NAm		
Cianficconi, F et al	2011	Trichopteran fauna in a region of Central Italy: Lazio	Canal	Native	Italy	EURO		
Casas, JJ et al	2011	The paradox of the conservation of an endangered fish species in a Mediterranean region under agricultural intensification	Canal	Conservation concern	Spain	EURO		
Szymura, TH et al	2011	BIODIVERSITY CONSERVATION OF THE VEGETATION ADJACENT TO WATERCOURSES INFLUENCED BY LAND RECLAMATION PRACTICIES: THE FLOODPLAIN OF THE ODRA RIVER (SILESIA, POLAND)	Ditch	Alien/native	Poland	EURO		

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Son, MO et al	2020	Caspian invaders vs. Ponto-Caspian locals - range expansion of invasive macroinvertebrates from the Volga Basin results in high biological pollution of the Lower Don River	Canal	Alien	Ponto-Caspian region	EURO	both	30
Wassens, S et al	2010	Habitat characteristics predict occupancy patterns of the endangered amphibian *Litoria raniformis* in flow-regulated flood plain wetlands	Canal	Conservation concern	Australia	OZ		
Sato, M et al	2010	Predicting the spatial distribution of the invasive piscivorous chub (Opsariichthys uncirostris uncirostris) in the irrigation ditches of Kyushu, Japan: a tool for the risk management of biological invasions	Ditch	Alien	Japan	JP		
Shaltout, KH et al	2010	Growth behaviour of the invasive species *Ipomoea carnea* in the Nile Delta, Egypt	Canal	Alien	Egypt	NAf		
Ahlers, AA et al	2010	Effects of flooding and riparian buffers on survival of muskrats (*Ondatra zibethicus*) across a flashiness gradient	Ditch	Native	US	NAm		
Leng, X et al	2010	Spatial variation in ditch bank plant species composition at the regional level: the role of environment and dispersal	Ditch	Conservation concern	Netherlands	EURO		
Cutway, HB & Ehrenfeld, JG	2010	The influence of urban land use on seed dispersal and wetland invasibility	Ditch	Alien/native	US	NAm		
Brandt, LA et al	2010	Spatial Distribution of Alligator Holes in the Central Everglades	Canal	Conservation concern	US	NAm		
Carlson, AJ & Rahel, FJ	2010	Annual Intrabasin Movement and Mortality of Adult Bonneville Cutthroat Trout among Complementary Riverine Habitats	Canal	Conservation concern	US	NAm		
Pierluissi, S et al	2010	Waterbird Nest Density and Nest Survival in Rice Fields of Southwestern Louisiana	Canal	Native	US	NAm		
Leng, X et al	2010	Synergy between nature reserves and agri-environmental schemes in enhancing ditch bank target species plant diversity	Ditch	Conservation concern	Netherlands	EURO		
Hinojosa-Garro, D et-al	2010	Influence of macrophyte spatial architecture on periphyton and macro-invertebrate community structure in shallow water bodies under contrasting land management	Ditch	Native	UK	BI		
Kano, Y et al	2010	Distribution of the oriental weatherloach, *Misgurnus anguillicaudatus*, in paddy fields and its implications for conservation in Sado Island, Japan	Ditch	Native	Japan	JP		
Brooks, WR & Jordan, RC	2010	Enhanced interspecific territoriality and the invasion success of the spotted tilapia (*Tilapia mariae*) in South Florida	Canal	Alien	US	NAm		
Gillis, NC et al	2010	Spatial ecology of adult muskellunge (*Esox masquinongy*) in the urban Ottawa reach of the historic Rideau Canal, Canada	Canal	Native	Canada	NAm		
Negishi, JN & Kayaba, Y	2010	Size-specific growth patterns and estimated longevity of the unionid mussel (Pronodularia japanensis)	Both	Conservation concern	Japan	JP		
Messiaen, M et al	2010	Alien macrocrustaceans in freshwater ecosystems in the eastern part of Flanders (Belgium)	Canal	Alien	Belgium	EURO		
Lindgren, C et al	2010	The Biology of Invasive Alien Plants in Canada. 11. *Tamarix ramosissima* Ledeb., *T. chinensis* Lour. and hybrids	Ditch	Alien	Canada	NAm		
Strayer, DL	2010	Alien species in fresh waters: ecological effects, interactions with other stressors, and prospects for the future	Canal	Alien	Global	Global		
Yue, GH et al	2010	High prevalence of multiple paternity in the invasive crayfish species, Procambarus clarkii	Ditch	Alien	China	EAs		
Van Geert, A et al	2010	Do linear landscape elements in farmland act as biological corridors for pollen dispersal?	Ditch	Native	Belgium	EURO		
Hohausova, E et al	2010	Fish dispersal in a seasonal wetland: influence of anthropogenic structures	Ditch	Alien/native	US	NAm		
Longoni, V	2010	Rice Fields and Waterbirds in the Mediterranean Region and the Middle East	Ditch	Conservation concern	Mediterranean and Middle East	EURO, MEa		
Hossain, MAR & Wahab, MA	2010	THE DIVERSITY OF CYPRINIFORMS THROUGHOUT BANGLADESH: PRESENT STATUS AND CONSERVATION CHALLENGES	Canal	All	Bangladesh	SAs		
Pierluissi, S	2010	Breeding Waterbirds in Rice Fields: A Global Review	Both	Conservation concern	Global	Global		

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Murie, DJ	2009	Variable growth and longevity of yellow bullhead (*Ameiurus natalis*) in the Everglades of south Florida, USA	Canal	Native	US	NAm		
Leuven, RSEW et al	2009	The river Rhine: a global highway for dispersal of aquatic invasive species	Canal	Alien	Europe	EURO		
Fukuda, S	2009	Consideration of fuzziness: Is it necessary in modelling fish habitat preference of Japanese medaka (*Oryzias latipes*)?	Canal	Conservation concern	Japan	JP		
Colvin, R et al	2009	Fish Use of Intermittent Watercourses Draining Agricultural Lands in the Upper Willamette River Valley, Oregon	Ditch	All	US	NAm		
Aavik, T & Liira, J	2009	Agrotolerant and high nature-value species-Plant biodiversity indicator groups in agroecosystems	Ditch	Native	Estonia	EURO		
Murie, DJ et al	2009	Age, differential growth and mortality rates in unexploited populations of Florida gar, an apex predator in the Florida Everglades	Canal	Native	US	NAm		
Onikura, N et al	2009	Habitat Use in Irrigation Channels by the Golden Venus Chub (*Hemigrammocypris rasborella*) at Different Growth Stages	Ditch	Conservation concern	Japan	JP		
Liu, CH & Yu, D	2009	The bud and root sprouting capacity of *Alternanthera philoxeroides* after over-wintering on sediments of a drained canal	Canal	Alien	China	EAs		
Vermonden, K et al	2009	Urban drainage systems: An undervalued habitat for aquatic macroinvertebrates	Both	All	Netherlands	EURO		
Muturi, EJ et al	2009	Spatiotemporal dynamics of immature culicines (subfamily Culicinae) and their larval habitats in Mwea Rice Scheme, Kenya	Both	Native	Kenya	EAf		
Bertolino, S et al	2009	Modelling the distribution of an introduced species: The coypu *Myocastor coypus* (Mammalia, Rodentia) in Piedmont region, NW Italy	Canal	Alien	Italy	EURO		
Al Sherif, EA	2009	Ecological Studies on Hydrophytic Vegetation of Irrigation and Drainage Canal Systems in Beni Suef, Egypt	Canal	Native	Egypt	NAf		
Poulet, N et al	2009	Genetic structure and dynamics of a small introduced population: the pikeperch, Sander lucioperca, in the Rhone delta	Canal	Alien	France	EURO		
Schekkerman, H et al	2009	Mortality of Black-tailed Godwit *Limosa limosa* and Northern Lapwing *Vanellus vanellus* chicks in wet grasslands: influence of predation and agriculture	Ditch	Native	Netherlands	EURO		
Peterman, WE & Ryan, TJ	2009	Basking Behaviour of Emydid Turtles (Chysemys picta, *Graptemys geographica*, and *Trachemys scripta*) in an Urban Landscape	Canal	Native	US	NAm		
Messyasz, B & Rybak, A	2009	The distribution of green algae species from the Ulva genera (syn. Enteromorpha; Chlorophyta) in Polish inland waters	Ditch	Native	Poland	EURO		
Tessier, M et al	2009	Odonata communities in an agricultural lowland in the South of France	Ditch	Conservation concern	France	EURO		
Pierluissi, S & King, SL	2008	Relative Nest Density, Nest Success, and Site Occupancy of King Rails in Southwestern Louisiana Rice Fields	Canal	Conservation concern	US	NAm		
Cucherousset, J et al	2008	SELECTIVE USE AND SPATIAL DISTRIBUTION OF NATIVE AND NON-NATIVE FISH IN WETLAND HABITATS	Canal	All	France	EURO		
Suzuki, T et al	2008	Genetic identification of larvae and juveniles reveals the difference in the spawning site among Cyprininae fish species/subspecies in Lake Biwa	Ditch	Native	Japan	JP		
Brzezinski, M et al	2008	Do otters and mink compete for access to foraging sites? A winter case study in the Mazurian Lakeland, Poland	Canal	All	Poland	EURO		
Gomez, I & Araujo, R	2008	Channels and ditches as the last shelter for freshwater mussels: the case of Margaritifera auricularia and other naiads inhabiting the mid Ebro River Basin, Spain	Both	Conservation concern	Spain	EURO		
Roberts, JJ & Rahel, FJ	2008	Irrigation canals as sink habitat for trout and other fishes in a Wyoming drainage	Canal	All	US	NAm		
Dure, MI et al	2008	Diversity of amphibians in rice fields from northeastern Argentina	Ditch	Native	Argentina	SAm		
Herzon, I & Helenius, J	2008	Agricultural drainage ditches, their biological importance and functioning	Ditch	Conservation concern	Global	Global		

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Davies, B et al	2008	Comparative biodiversity of aquatic habitats in the European agricultural landscape	Ditch	Conservation concern	Europe	EURO		
Goulder, R	2008	Conservation of aquatic plants in artificial watercourses: are main drains a substitute for vulnerable navigation canals?	Canal	Alien/native	UK	BI		
Jodoin, Y et al	2008	Highways as corridors and habitats for the invasive common reed *Phragmites australis* in Quebec, Canada	Ditch	Alien	Canada	NAm		
De Bie, T et al	2008	A comparative analysis of cladoceran communities from different water body types: patterns in community composition and diversity	Ditch	Native	Belgium	EURO		
Davies, BR et al	2008	A comparison of the catchment sizes of rivers, streams, ponds, ditches and lakes: implications for protecting aquatic biodiversity in an agricultural landscape	Ditch	Conservation concern	UK	BI		
Karatayev, AY et al	2008	Past, current, and future of the central European corridor for aquatic invasions in Belarus	Canal	Alien	Belarus	EURO		
Stubbington, R et al	2008	The first occurrence of the Ponto-Caspian invader, Hemimysis anomala G. O. Sars, 1907 (Mysidacea) in the U.K	Canal	Alien	UK	BI		
Wildermuth, H	2008	Habitat requirements of Orthetrum coerulescens and management of a secondary habitat in a highly man-modified landscape (Odonata: Libellulidae)	Ditch	Native	Switzerland	EURO		
Kazantzidis, S & Goutner, V	2008	Abundance and habitat use by herons (Ardeidae) in the Axios Delta, northern Greece	Canal	Native	Greece	EURO		
Cowley, DE et al	2007	Fish assemblages and seasonal movements of fish in irrigation canals and river reaches of the middle Rio Grande, New Mexico (USA)	Canal	All	US	NAm		
Mukai, Y & Ishii, M	2007	Habitat utilization by the giant water bug, Appasus (=Diplonychus) major (Hemiptera: Belostomatidae), in a traditional rice paddy water system in northern Osaka, central Japan	Ditch	Native	Japan	JP		
Molloy, DP et al	2007	Discovery of Dreissena rostriformis bugensis (Andrusov 1897) in Western Europe	Canal	Alien	Netherlands	EURO		
Niggebrugge, K et al	2007	Applying landscape ecology to conservation biology: Spatially explicit analysis reveals dispersal limits on threatened wetland gastropods	Ditch	Conservation concern	UK	BI		
Carlson, AJ & Rahel, FJ	2007	A basinwide perspective on entrainment of fish in irrigation canals	Canal	All	US	NAm		
Musil, J et al	2007	Seasonal dynamics of fish assemblage in a pond canal	Canal	All	Czech	EURO		
Hirose, M & Mawatari, SF	2007	Freshwater Bryozoa of Tonle Sap, Cambodia	Moat	Native	Cambodia	SEA		
Devi, NP & Jauhari, RK	2007	Mosquito species associated within some western Himalayas phytogeographic zones in the Garhwal region of India	Ditch	Native	India	SAs		
Krebs, JM et al	2007	Altered mangrove wetlands as habitat for estuarine nekton: Are dredged channels and tidal creeks equivalent?	Ditch	Alien/native	US	NAm		
Rahel, FJ	2007	Biogeographic barriers, connectivity and homogenization of freshwater faunas: it's a small world after all	Canal	Alien/native	Global	Global		
Makrakis, S et al	2007	The canal da piracema at itaipu dam as a fish pass system	Canal	Native	Brazil	SAm		
Lubcke, GM & Wilson, DS	2007	Variation in shell morphology of the Western Pond Turtle (*Actinemys marmorata* Baird and Girard) from three aquatic habitats in northern California	Canal	Conservation concern	US	NAm		
Zuffi, MAL et al	2007	Reproductive strategies and body shape in the European pond turtle (Emys orbicularis) from contrasting habitats in Italy	Canal	Conservation concern	Italy	EURO		
Piha, H et al	2007	Anuran abundance and persistence in agricultural landscapes during a climatic extreme	Ditch	Native	Finland	EURO		
Kozhara, AV et al	2007	Range extension and conservation status of the bitterling, *Rhodeus sericeus amarus* in Russia and adjacent countries	Canal	Alien	Russia and Ukraine	RU, EURO		

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Fernald, AG et al	2007	Hydrologic, riparian, and agroecosystem functions of traditional Acequia irrigation systems	Ditch	Native	US	NAm		
Nowak, A et al	2007	Rare and threatened pondweed communities in anthropogenic water bodies of Opole Silesia (SW Poland)	Both	Conservation concern	Poland	EURO		
Kraszewski, A & Zdanowski, B	2007	Sinanodonta woodiana (Lea, 1834) (Mollusca) - A new mussel species in Poland: Occurence and habitat preferences in a heated lake system	Canal	Alien	Poland	EURO		
Morley, NJ & Lewis, JW	2006	Anthropogenic pressure on a moll uscan-trematode community over a long-term period in the Basingstoke Canal, UK, and its implications for ecosystem health	Canal	Native	UK	BI		
Cucherousset, J et al	2006	Habitat use of an artificial wetland by the invasive catfish *Ameiurus melas*	Ditch	Alien	France	EURO		
Spence, R et al	2006	The distribution and habitat preferences of the zebrafish in Bangladesh	Both	Native	Bangladesh	SAs		
Sumner, AT	2006	Distribution of certain molluscs in the lowland canals of Scotland	Canal	Native	UK	BI		
Fukuda, S et al	2006	Fuzzy neural network model for habitat prediction and HEP for habitat quality estimation focusing on Japanese medaka (Oryzias latipes) in agricultural canals	Canal	Conservation concern	Japan	JP		
Sundar, KSG	2006	Flock size, density and habitat selection of four large waterbirds species in an agricultural landscape in Uttar Pradesh, India: Implications for management	Canal	Conservation concern	India	SAs		
Tan, KS & Morton, B	2006	The invasive Caribbean bivalve Mytilopsis sallei (Dreissenidae) introduced to Singapore and Johor Bahru, Malaysia	Canal	Alien	Singapore	SEA		
Orlowski, G	2006	Habitat selection and winter food resources of the Water Pipit *Anthus spinoletta* in south-western Poland	Ditch	Native	Poland	EURO		
Marti, GA et al	2006	Predation efficiency of indigenous larvivorous fish species on *Culex pipiens* L. larvae (Diptera: Culicidae) in drainage ditches in Argentina	Ditch	Native	Argentina	SAm		
Nehring, S	2006	Four arguments why so many alien species settle into estuaries, with special reference to the German river Elbe	Canal	Alien	Germany	EURO		
Clements, R et al	2006	Importance of reservoirs for the conservation of freshwater molluscs in a tropical urban landscape	Canal	Native	Singapore	SEA		
Takeda, M et al	2006	The habitat requirement of the Genji-firefly Luciola cruciata (Coleoptera: Lampyridae), a representative endemic species of Japanese rural landscapes	Ditch	Conservation concern	Japan	JP		
Lanszki, J & Szeles, GL	2006	Feeding habits of otters living on three moors in the Pannonian ecoregion (Hungary)	Canal	Conservation concern	Hungary	EURO		
Waldman, JR et al	2006	Biodiversity and zoogeography of the fishes of the Hudson River watershed and estuary	Canal	Alien/native	US	NAm		
Puky, M & Schad, P	2006	*Orconectes limosus* colonises new areas fast along the Danube in Hungary	Canal	Alien	Hungary	EURO		
Chlyeh, G et al	2006	Spatio-temporal distribution of freshwater snail species in relation to migration and environmental factors in an irrigated area from Morocco	Canal	Native	Morocco	NAf		
Davis, GM et al	2006	Ecogenetics of shell sculpture in Oncomelania (Gastropoda) in canals of Hubei, China, and relevance for schistosome transmission	Canal	Native	China	EAs		
Maheu-Giroux, M & de Blois, S	2005	Mapping the invasive species Phragmites australis in linear wetland corridors	Ditch	Alien	Canada	NAm		
Sluys, R et al	2005	A new and alien species of “oyster leech” (Platyhelminthes, Polycladida, Stylochidae) from the brackish North Sea Canal, The Netherlands	Canal	Alien	Netherlands	EURO		
Poulet, N et al	2005	Pikeperch habitat use within a canal network in spring	Canal	Native	France	EURO		
Johansson, M et al	2005	The influence of landscape structure on occurrence, abundance and genetic diversity of the common frog, Rana temporaria	Ditch	Native	Sweden	EURO		

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Jaeger, ME et al	2005	Seasonal movements, habitat use, aggregation, exploitation, and entrainment of saugers in the Lower Yellowstone River: An empirical assessment of factors affecting population recovery	Canal	Conservation concern	US	NAm		
Dickert, C	2005	Giant garter snake surveys at some areas of historic occupation in the grassland ecological area, Merced Co. and Mendota Wildlife Area, Fresno Co., California	Canal	Conservation concern	US	NAm		
Miaud, C & Sanuy, D	2005	Terrestrial habitat preferences of the natterjack toad during and after the breeding season in a landscape of intensive agricultural activity	Ditch	Native	Spain	EURO		
Bryan, MB et al	2005	Patterns of invasion and colonization of the sea lamprey (*Petromyzon marinus*) in North America as revealed by microsatellite genotypes	Canal	Alien	Canada-US	NAm		
Watson, AM & Ormerod, SJ	2005	The distribution and conservation of threatened sphaeriidae on British grazing marshland	Ditch	Conservation concern	UK	BI		
Walsh, HJ et al	2005	Early life history of blueback herring and alewife in the lower Roanoke River, North Carolina	Canal	Native	US	NAm		
Pimentel, D	2005	Aquatic nuisance species in the New York State Canal and Hudson River systems and the Great Lakes Basin: An economic and environmental assessment	Canal	Alien	US	NAm		
Rouquette, JR & Thompson, DJ	2005	Habitat associations of the endangered damselfly, Coenagrion mercuriale, in a water meadow ditch system in southern England	Ditch	Conservation concern	UK	BI		
Unwin, MJ et al	2005	Quantifying production of salmon fry in an unscreened irrigation system: A case study on the Rangitata River, New Zealand	Canal	Alien	NZ	NZ		
Conner, CA et al.	2005	Descriptive ecology of a turtle assemblage in an urban landscape	Canal	Native	US	NAm		
Nagorskaya, L & Keyser, D	2005	Habitat diversity and ostracod distribution patterns in Belarus	Canal	Native	Belarus	EURO		
Wicknick, JA et al	2005	An amphibian survey of Killbuck Marsh Wildlife Area, Ohio	Ditch	Native	US	NAm		
Habit, E et al	2005	Trophic ecology and reproductive aspects of *Trichomycterus areolatus* (Pisces, Trichomycteridae) in irrigation canal environments.	Canal	Native	Chile	SAm		
Cooper, A et al	2005	Vegetation, water beetles and habitat isolation in abandoned lowland bog drains and peat pits	Ditch	Conservation concern	UK	BI		
Lobos, G & Jaksic, FM	2005	The ongoing invasion of African clawed frogs (Xenopus laevis) in Chile: causes of concern	Canal	Alien	Chile	SAm		
Mason, CF & MacDonald, SM	2005	The bird assemblage of coastal borrowdykes in relation to habitat features	Ditch	Native	UK	BI		
Peeters, ETHM	2005	Ditch maintenance and biodiversity of macrophytes in the Netherlands	Ditch	Native	Netherlands	EURO		
Bried, JT & Ervin, GN	2005	Distribution of adult Odonata among localized wetlands in east-central Mississippi	Ditch	Native	US	NAm		
Sundar, KSG	2004	Group size and habitat use by Black-necked Storks *Ephippiorhynchus asiaticus* in an agriculture-dominate landscape in Uttar Pradesh, India	Canal	Conservation concern	India	SAs		
Holeck, KT et al	2004	Bridging troubled waters: Biological invasions, transoceanic shipping, and the Laurentian Great Lakes	Canal	Alien	Canada-US	NAm		
Ficetola, GF & De Bernardi, F	2004	Amphibians in a human-dominated landscape: the community structure is related to habitat features and isolation	Both	Conservation concern	Italy	EURO		
Matsuyama-Serisawa, K et al	2004	Growth, maturation and photosynthesis of the brackish water alga Rhizoclonium sp. (Cladophoraceae, Chlorophyta) in relation to salinity	Canal	Native	Japan	JP		
Laffaille, P et al	2004	Habitat preferences of different European eel size classes in a reclaimed marsh: A contribution to species and ecosystem conservation	Ditch	Conservation concern	France	EURO		

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Appendix Table A1 (*continued*)

Author	Year	Title	Structure	Species/community	Location	Location 2	Row labels	Count of structure
Son, MO et al	2020	Caspian invaders vs. Ponto-Caspian locals - range expansion of invasive macroinvertebrates from the Volga Basin results in high biological pollution of the Lower Don River	Canal	Alien	Ponto-Caspian region	EURO	both	30
Watson, AM & Ormerod, SJ	2004	The distribution of three uncommon freshwater gastropods in the drainage ditches of British grazing marshes	Ditch	Conservation concern	UK	BI		
Schrank, AJ & Rahel, FJ	2004	Movement patterns in inland cutthroat trout (*Oncorhynchus clarki utah*): management and conservation implications	Both	Conservation concern	US	NAm		
Barbaresi, S et al	2004	Factors inducing the intense burrowing activity of the red-swamp crayfish, Procambarus clarkii, an invasive species	Ditch	Alien	Italy	EURO		
Watson, AM & Ormerod, SJ	2004	The microdistribution of three uncommon freshwater gastropods in the drainage ditches of British grazing marshes	Ditch	Conservation concern	UK	BI		
Williams, P et al	2004	Comparative biodiversity of rivers, streams, ditches and ponds in an agricultural landscape in Southern England	Ditch	Conservation concern	UK	BI		
Kotenko, T	2004	Distribution, habitats, abundance and problems of conservation of the European pond turtle (Emys orbicularis) in the Crimea (Ukraine): first results	Canal	Conservation concern	Ukraine	EURO		
Puky, M et al	2004	Distribution of Emys orbicularis in Hungary with notes on related conservational and environmental education activities	Canal	Conservation concern	Hungary	EURO		
Leao, M et al	2004	Patterns of fish community structure associated with created wetlands in the Upper White River watershed	Ditch	Alien/native	US	NAm		
De Francesco, CG & Isla, FI	2004	Reproductive period and growth rate of the freshwater snail Heleobia parchappii (d'Orbigny, 1835) (Gastropoda: Rissooidea) in a shallow brackish habitat (Buenos Aires Province, Argentina)	Canal	Native	Argentina	SAm		
Blomqvist, MM et al	2004	Restoration of ditch bank plant species richness: The potential of the soil seed bank	Ditch	Conservation concern	Netherlands	EURO		
Connolly, RM	2003	Differences in trophodynamics of commercially important fish between artificial waterways and natural coastal wetlands	Canal	Native	Australia	OZ		
Boedeltje, G et al	2003	Potential role of propagule banks in the development of aquatic vegetation in backwaters along navigation canals	Canal	Native	Netherlands	EURO		
Schmetterling, DA	2003	Reconnecting a fragmented river: Movements of westslope cutthroat trout and bull trout after transport upstream of Milltown Dam, Montana	Ditch	Conservation concern	US	NAm		
Carpentier, A et al	2003	Trends of a bitterling (Rhodeus sericeus) population in a man-made ditch network	Ditch	Conservation concern	France	EURO		
McNeely, DL & Wade, CE	2003	Relative abundance of the gynogen *Poecilia formosa* and its sexual host *Poecilia latipinna* (Teleostei: Poeciliidae) in some southern Texas habitats	Ditch	Native	US	NAm		
Chittapun, S et al	2003	Contribution to the knowledge of Thai microfauna diversity: notes on rare peat swamp Rotifera, with the description of a new Lecane Nitzsch, 1872	Canal	Native	Thailand	SEA		
Donath, TW et al	2003	The impact of site conditions and seed dispersal on restoration success in alluvial meadows	Ditch	Conservation concern	Germany	EURO		
Park, YS et al	2003	Patterning and predicting aquatic macroinvertebrate diversities using artificial neural network	Both	Native	Netherlands	EURO		
Teo, SLH & Able, KW	2003	Habitat use and movement of the mummichog (*Fundulus heteroclitus*) in a restored salt marsh	Ditch	Native	US	NAm		
Blomqvist, MM et al	2003	Declining plant species richness of grassland ditch banks - a problem of colonization or extinction?	Ditch	Native	Netherlands	EURO		
Armitage, PD et al	2003	Ditch communities: a major contributor to floodplain biodiversity	Ditch	Conservation concern	UK	BI		
Katano, O et al	2003	Species diversity and abundance of freshwater fishes in irrigation ditches around rice fields	Ditch	Native	Japan	JP		

(*continued on next page*)

Appendix Table A1 (*continued*)

Author	Year	Title	Structure	Species/community	Location	Location 2	Row labels	Count of structure
Son, MO et al	2020	Caspian invaders vs. Ponto-Caspian locals - range expansion of invasive macroinvertebrates from the Volga Basin results in high biological pollution of the Lower Don River	Canal	Alien	Ponto-Caspian region	EURO	both	30
Vilbaste, S & Truu, J	2003	Distribution of benthic diatoms in relation to environmental variables in lowland streams	Ditch	Native	Estonia	EURO		
Arlinghaus, R & Wolter, C	2003	Amplitude of ecological potential: chub *Leuciscus cephalus* (L.) spawning in an artificial lowland canal	Canal	Native	Germany	EURO		
Mcelroy, TC et al	2003	Extinction-colonization dynamics structure genetic variation of spotted sunfish (*Lepomis punctatus*) in the Florida Everglades	Canal	Native	US	NAm		
Boutin, C et al	2003	Importance of riparian habitats to flora conservation in farming landscapes of southern Quebec, Canada	Ditch	Native	Canada	NAm		
Holcik, J	2003	Changes in the fish fauna and fisheries in the Slovak section of the Danube River: a review	Canal	All	Slovakia	EURO		
Acou, A et al	2003	Silvering of female eels (Anguilla anguilla) in two sub-populations of the Rhone Delta	Canal	Conservation concern	France	EURO		
Sullivan, WP et al	2003	The sea lamprey in Lake Erie: a case history	Canal	Alien	Canada-US	NAm		
Culling, MA et al	2003	Substratum preferences and diel activity patterns of spined loach *Cobitis taenia* in England: implications for conservation management	Ditch	Conservation concern	UK	BI		
Reise, K	2003	Metapopulation structure in the lagoon cockle *Cerastoderma lamarcki* in the northern Wadden Sea	Ditch	Native	Germany and Danmark	EURO		
Bruno, MC et al	2003	Copepod communities from surface and ground waters in the Everglades, South Florida	Canal	Native	US	NAm		
Arlinghaus, R et al	2002	Fish recruitment in a canal with intensive navigation: implications for ecosystem management	Canal	Native	Germany	EURO		
Ito, K	2002	Environmental factors influencing overwintering success of the golden apple snail, Pomacea canaliculata (Gastropoda: Ampullariidae), in the northernmost population of Japan	Canal	Alien	Japan	JP		
Dietz-Brantley, SE et al	2002	Invertebrates that aestivate in dry basins of Carolina bay wetlands	Ditch	Native	US	NAm		
Grillet, ME et al	2002	Community structure of Neotropical wetland insects in Northern Venezuela. II. Habitat type and environmental factors	Canal	Native	Venezuela	SAm		
Masters, JEG et al	2002	Habitat utilization by pike Esox lucius L. during winter floods in a southern English chalk river	Ditch	Native	UK	BI		
Geertsema, W & Sprangers, JTCM	2002	Plant distribution patterns related to species characteristics and spatial and temporal habitat heterogeneity in a network of ditch banks	Ditch	Native	Netherlands	EURO		
Brown, AW & Brown, LM	2002	Prefledging survival of Mute Swan *Cygnus olor* cygnets in the Lothians, UK	Canal	Conservation concern	UK	BI		
bij de Vaate, A et al	2002	Geographical patterns in range extension of Ponto-Caspian macroinvertebrate species in Europe	Canal	Alien	Europe	EURO		
Grigorovich, IA et al	2002	Patterns and mechanisms of aquatic invertebrate introductions in the Ponto-Caspian region	Canal	Alien	Europe	EURO		
Swamy, V et al	2002	Macroinvertebrate and fish populations in a restored impounded salt marsh 21 years after the reestablishment of tidal flooding	Ditch	Native	US	NAm		
Rorabaugh, JC et al	2002	Continued invasion by an introduced frog (*Rana berlandieri*): Southwestern Arizona, southeastern California, and Rio Colorado, Mexico	Both	Alien	US-Mexico	NAm, CAm		
Greenwood, A et al	2002	Geographical distribution and habitat occurrence of the Water Shrew (*Neomys fodiens*) in the Weald of South-East England	Both	Conservation concern	UK	BI		
Milsom, TP et al	2002	Management of coastal grazing marshes for breeding waders: the importance of surface topography and wetness	Ditch	Conservation concern	UK	BI		

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Appendix Table A1 (*continued*)

Author	Year	Title	Structure	Species/community	Location	Location 2	Row labels	Count of structure
Son, MO et al	2020	Caspian invaders vs. Ponto-Caspian locals - range expansion of invasive macroinvertebrates from the Volga Basin results in high biological pollution of the Lower Don River	Canal	Alien	Ponto-Caspian region	EURO	both	30
Kowalik, W	2002	The occurrence of water mites (Hydrachnidia, Acari) in saline waters from a stone coal-mine in Bogdanka (South-Eastern Poland)	Canal	Native	Poland	EURO		
Jakab, T et al	2002	Dragonfly assemblages of a shallow lake type reservoir (Tisza-to, Hungary) and its surroundings	Canal	Native	Hungary	EURO		
Valladares, LF et al	2002	The assemblages of aquatic Coleoptera from shallow lakes in the northern Iberian Meseta: Influence of environmental variables	Canal	Native	Spain	EURO		
Maeda, T et al	2001	Patterns of bird abundance and habitat use in rice fields of the Kanto Plain, central Japan	Ditch	Conservation concern	Japan	JP		
Bleeker, W & Hurka, H	2001	Introgressive hybridization in Rorippa (Brassicaceae): gene flow and its consequences in natural and anthropogenic habitats	Ditch	Native	Germany	EURO		
Willby, NJ et al	2001	Inter-relationships between standing crop, biodiversity and trait attributes of hydrophytic vegetation in artificial waterways	Canal	Conservation concern	UK	BI		
Rosecchi, E et al	2001	Can life-history traits predict the fate of introduced species? A case study on two cyprinid fish in southern France	Canal	Alien/native	France	EURO		
Babik, W & Rafinski, J	2001	Amphibian breeding site characteristics in the Western Carpathians, Poland	Ditch	Conservation concern	Poland	EURO		
Devin, S et al	2001	Dikerogammarus villosus (Amphipoda: Gammaridae): another invasive species newly established in the Moselle river and French hydrosystems	Canal	Alien	France	EURO		
Goumghar, MD et al	2001	Influence of aestivation on the survival of Galba truncatula (Mollusca: Gasteropoda) populations according to altitude	Ditch	Native	France	EURO		
Costil, K et al	2001	Biodiversity of aquatic gastropods in the Mont St-Michel basin (France) in relation to salinity and drying of habitats	Canal	Native	France	EURO		
Lounibos, LP	2001	Boom-or-bust development of a predatory mosquito in temporary aquatic habitats of Florida, USA	Ditch	Native	US	NAm		
Walters, NF et al	2001	Nest success and nesting habitats of mottled ducks on the Mississippi river delta in Louisiana	Canal	Conservation concern	US	NAm		
Downhower, JF et al	2000	Life history variation in female Gambusia hubbsi	Ditch	Native	Bahamas	CAm		
Araujo, R & Ramos, MA	2000	Status and conservation of the giant European freshwater pearl mussel (Margaritifera auricularia) (Spengler, 1793) (Bivalvia: Unionoidea)	Canal	Conservation concern	Spain	EURO		
Marsden, SJ & Bellamy, GS	2000	Microhabitat characteristics of feeding sites used by diving duck Aythya wintering on the grossly polluted Manchester Ship Canal, UK	Canal	Conservation concern	UK	BI		
Meyer, L & Hinrichs, D	2000	Microhabitat preferences and movements of the weatherfish, *Misgurnus fossilis*, in a drainage channel	Both	Conservation concern	Germany	EURO		
Barndt, SA & Kaya, CM	2000	Reproduction, growth, and winter habitat of Arctic grayling in an intermittent canal	Canal	Native	US	NAm		
Maisonneuve, C et al	2000	Habitat use, movements, and survival of American Black Duck, *Anas rubripes*, and Mallard, A-platyrhynchos, broods in agricultural landscapes of southern Quebec	Ditch	Conservation concern	Canada	NAm		
Gherardi, F et al	2000	Spatial and temporal patterns in the movement of Procambarus clarkii, an invasive crayfish	Canal	Alien	Italy	EURO		
Galatowitsch, SM et al	2000	The vegetation of wet meadows in relation to their land-use	Ditch	Alien/native	US	NAm		
Marmonier, P et al	2000	Interstitial fauna in newly-created floodplain canals of a large regulated river	Canal	Native	France	EURO		
Painter, D	1999	Macroinvertebrate distributions and the conservation value of aquatic Coleoptera, Mollusca and Odonata in the ditches of traditionally managed and grazing fen at Wicken Fen, UK	Ditch	Conservation concern	UK	BI		

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Appendix Table A1 (*continued*)

Author	Year	Title	Structure	Species/community	Location	Location 2	Row labels	Count of structure
Son, MO et al	2020	Caspian invaders vs. Ponto-Caspian locals - range expansion of invasive macroinvertebrates from the Volga Basin results in high biological pollution of the Lower Don River	Canal	Alien	Ponto-Caspian region	EURO	both	30
Vareille-Morel, C et al	1999	The characteristics of habitats colonized by three species of Lymnaea (Mollusca) in swampy meadows on acid soil: their interest for control of fasciolosis	Ditch	Native	France	EURO		
Feunteun, E et al	1999	Fish communities of Atlantic littoral reclaimed marshes: A heritage to be managed? The case of Bourgneuf-Machecoul marsh (Western France).	Ditch	All	France	EURO		
Husband, BC & Barrett, SCH	1998	Spatial and temporal variation in population size of *Eichhornia paniculata* in ephemeral habitats: implications for metapopulation dynamics	Ditch	Native	Brazil	SAm		
Williams, DD & Williams, NE	1998	Freshwater invertebrates from the Bermuda Islands and their zoogeographical affinities	Ditch	Alien/native	Bermuda	BER		
Whitfield, M et al	1998	The ecology and conservation of the glutinous snail Myxas glutinosa (Muller) in Great Britain: A review	Ditch	Conservation concern	UK	BI		
Killeen, IJ	1998	An assessment of the mollusc faunas of grazing marsh ditches using numerical indices, and their application for monitoring and conservation	Ditch	Conservation concern	UK	BI		
Ferreira, MT et al	1998	Aquatic weed assemblages in an Iberian drainage channel system and related environmental factors	Canal	Alien/native	Portugal	EURO		
Peters, KM et al	1998	Reproduction and early life history of common snook, *Centropomus undecimalis* (Bloch), in Florida	Canal	Native	US	NAm		
Khallaayoune, K et al	1998	Distribution of Bulinus truncatus, the intermediate host of Schistosoma haematobium, in an irrigation system in Morocco	Canal	Native	Morocco	NAf		
Moy, PB	1998	Chicago sanitary and ship canal dispersal barrier	Canal	Alien	US	NAm		
Khedr, AHA & Hegazy, AK	1998	Ecology of the rampant weed *Nymphaea lotus* L. Willdenow in natural and ricefield habitats of the Nile delta, Egypt	Canal	Native	Egypt	NAf		
Sanoamuang, LO	1998	Rotifera of some freshwater habitats in the floodplain of the River Nan, northern Thailand	Canal	Native	Thailand	SEA		
Grigorovich, IA et al	1998	*Bythotrephes longimanus* in the Commonwealth of Independent States: variability, distribution and ecology	Canal	Native	Eurasia	EURO, ASIA		
Dehus, P et al	1998	Notes on the occurrence of the calico crayfish (*Orconectes immunis*) in Germany	Canal	Alien	Germany	EURO		
Donnelly, RE et al	1998	Movements of a bream (*Abramis brama* (L.)), rudd x bream hybrid, tench (*Tinca tinca* (L.)) and pike (Esox lucius (L.)) in an Irish canal habitat	Canal	Native	Ireland	BI		
Mori, G et al	1998	The ciliate communities of different habitats of Lake Massaciuccoli (Tuscany): Species composition and distribution	Canal	Native	Italy	EURO		
Ernegger, T et al	1998	A natural stream created by human engineering: Investigations on the succession of the Marchfeld Canal in Austria	Canal	All	Austria	EURO		
Winemiller, KO & Anderson, AA	1997	Response of endangered desert fish populations to a constructed refuge	Canal	Conservation concern	US	NAm		
Barrett, SCH & Husband, BC	1997	Ecology and genetics of ephemeral plant populations: Eichhornia paniculata (Pontederiaceae) in northeast Brazil	Ditch	Native	Brazil	SAm		
Poizat, G & Crivelli, AJ	1997	Use of seasonally flooded marshes by fish in a Mediterranean wetland: Timing and demographic consequences	Canal	All	France	EURO		
Miller, SJ & Haynes, JM	1997	Factors limiting colonization of western New York creeks by the zebra mussel (*Dreissena polymorpha*)	Canal	Alien	US	NAm		
Mathieu, J et al	1997	Genetic differentiation of Niphargus rhenorhodanensis (Amphipoda) from interstitial and karst environments	Canal	Native	France	EURO		
Nelva, A	1997	The penetration of the nase, *Chondrostoma nasus* nasus (Pisces, Cyprinidae), in the French hydrographic network and its consequences.	Canal	Alien	France	EURO		

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Appendix Table A1 (*continued*)

Author	Year	Title	Structure	Species/community	Location	Location 2	Row labels	Count of structure
Son, MO et al	2020	Caspian invaders vs. Ponto-Caspian locals - range expansion of invasive macroinvertebrates from the Volga Basin results in high biological pollution of the Lower Don River	Canal	Alien	Ponto-Caspian region	EURO	both	30
Bohl, E	1997	An isolated population of the white-clawed crayfish (Austropotamobius pallipes) in the principality of Liechtenstein.	Ditch	Alien	Liechtenstein	EURO		
Caffrey, J & Monahan, C	1997	Natural aquatic plant colonization in a newly constructed Irish canal	Canal	Alien/native	Ireland	BI		
Novakova, J	1997	Retreat of halophytes in the Czech Republic: Agricultural, mining, and urbanization effects [The case of Dentated Melilot Melilotus dentata (Fabaceae)]	Ditch	Conservation concern	Czech	EURO		
Willby, NJ & Eaton, JW	1996	Backwater habitats and their role in nature conservation on navigable waterways	Canal	Native	UK	BI		
Simons, J & Nat, E	1996	Past and present distribution of stoneworts (Characeae) in the Netherlands	Ditch	Native	Netherlands	EURO		
Vareille, L et al	1996	Lymnaeid habitats in swampy meadows on acid soil: Effects of agricultural impacts	Ditch	Alien/native	France	EURO		
Fasola, M & Ruiz, X	1996	The value of rice fields as substitutes for natural wetlands for waterbirds in the Mediterranean region	Canal	Conservation concern	Europe	EURO		
Fasola, M et al	1996	Rice fields support a large portion of herons breeding in the Mediterranean region	Canal	Native	Europe	EURO		
Furse, JB et al	1996	Habitat use and movements of largemouth bass associated with changes in dissolved oxygen and hydrology in Kissimmee River, Florida	Canal	Native	US	NAm		
ROSECCHI, E & CRIVELLI, AJ	1995	SAND SMELT (ATHERINA-BOYERI) MIGRATION WITHIN THE WATER-SYSTEM OF THE CAMARGUE, SOUTHERN PRANCE	Canal	Native	France	EURO		
Smith, JP	1995	Foraging flights and habitat use of nesting wading birds (Ciconiiformes) at Lake Okeechobee, Florida	Ditch	Conservation concern	US	NAm		

Description: exclude water quality, hydrology, physics, soil only studies and methodology studies, exclude data paper; focus on aquatic ecosystem and species (including aquatic and semi-aquatic species, riparian vegetation, and waterbirds).
Year: 1995-2020.
Search strings: ((canal$ OR moat$ OR ditch* OR "artificial waterway$" OR "anthropogenic waterway$") AND (conserv* OR restor* OR rehabi* OR biodiversity OR ecosystem$ OR habitat$ OR corridor$)) OR ((artificial OR anthropogenic) AND (irrigat* OR navigat* OR drain*) AND (conserv* OR restor* OR rehabi* OR biodiversity OR ecosystem$ OR habitat$ corridor$)).

Appendix Table A2
Examples of the negative and positive ecological effects of canals.

Ecological effect	Location and species examined	Reference
Negative		
Possible corridors for invasive species	Laurentian Great Lakes. Non-native fishes	(Daniels, 2001)
	Severn and Thames Rivers, UK. Zebra mussels (*Dreissena polymorpha*), quagga mussels (*D. rostriformis bugensis*), Asian clams (*Corbicula fluminea*)	(Gallardo and Aldridge, 2018)
	Inland waters, Poland. Tubenose goby (*Protherorhinus marmoratus*), round goby (*Neogobius melanostomus*), racer goby (*N. gymnotrachelus*), monkey goby (*N. fluviatilis*)	(Grabowska et al., 2008)
	Peninsular India basins. Freshwater fishes	(Grant et al., 2012)
	European watersheds. Macroinvertebrates	(Leuven et al., 2009)
	European canals. Invertebrates and freshwater fishes	(Galil et al., 2007)
	Rhine-Main-Danube-Canal. Freshwater fishes	(Wolter and Röhr, 2010)
Possible corridors for isolated populations (reduce genetic diversity)	Rapel and Mataquito basins, Chile. Freshwater catfish (*Diplomystes* cf. *camposensis*)	(Muñoz-Ramírez et al., 2015)
Ecological traps	Albert Canal, Belgium. European eel (*Anguilla anguilla*), Atlantic salmon (*Salmo salar*)	(Vergeynst et al., 2019)
	Lemhi River subbasin, USA. Chinook salmon (*Oncorhynchus tshawytscha*)	(Walters et al., 2012)
	Sacramento and San Joaquin Rivers, USA. Chinook salmon	(Zeug and Cavallo, 2014)
Migration barrier	Navigation canals, Germany. Cyprinid fishes	(Wolter and Vilcinskas, 1998)
All of above	Review study	(Rahel, 2013)
Positive		
Novel habitat for common species and refuge for endangered species	Oder-Havel-Canal, Germany. Roach (*Rutilus rutilus*), perch (*Perca fluviatilis*)	(Arlinghaus et al., 2002)
	Wieprz-Krzna irrigation canal, Poland. Bitterling (*Rhodeus sericeus*)	(Przybylski and García-Berthou, 2004)
	Rio Grabde, USA. Freshwater fishes	(Cowley et al., 2007)
	Rideau Canal, Canada. Freshwater fishes	(Walker et al., 2010)
	Canals, Netherland. Smelt (*Osmerus eperlanus*), three-spined stickleback (*Gasterosteus aculeatus*), European eel	(Brevé et al., 2014)
	Irrigation canals in Colorado, USA. Riparian plants and aquatic macroinvertebrates	(Carlson et al., 2019)
	Irrigation canals, Slovakia. Aquatic macrophytes	(Dorotovičová, 2013)
	Canal Imperial de Aragón and Canal de Tauste, Spain. Freshwater mussels (*Margaritifera auricularia*, *Unio mancus*, *Potomida litoralis*, *Anodonta* sp.)	(Gómez and Araujo, 2008)
	Dortmund-Ems canal, Germany. Floodplain macrophytes	(Harvolk et al., 2014)
	Wind River, USA. Burbot (*Lota lota*)	(Hooley-Underwood et al., 2018)
	Irrigation canals and ditches, Japan. Threatened freshwater fishes	(Onikura, 2015)
Ecological corridor and novel habitat/spawning ground	Irrigation and hydroelectric canals in Durance River, France. Cyprinids (*Parachondrostoma toxostoma*, *Chondrostoma nasus*)	(Guivier et al., 2019)
	Navigation canals. Insects	(Villemey et al., 2018)
Migration pathway and novel spawning ground	Reddal canal, Norway. Atlantic herring (*Clupea harengus*)	(Eggers et al., 2015)
Migration pathway	Lake Washington Ship Canal, USA. Sockeye (*O. nerka*), coho (*O. kisutch*), Chinook, steelhead (*O. mykiss*) salmons	(Tabor et al., 2007)
	Albert Canal, Belgium. European eel	(Nzau Matondo et al., 2017; Verhelst et al., 2018)
All of above	Review study	(Chester and Robson, 2013)

Appendix Table A3
Examples in Fig. 2.

Canal	Country	Freshwater ecoregion (one: within; two: direct connection)	Main function (past/current)	UNESCO world heritage
Rideau Canal	Canada	"St Lawrence" + "Laurentian Great Lakes"	Defense and transportation/recreation	Yes
Chicago Sanitary and Ship Canal	US	"Laurentian Great Lakes" + "Upper Mississippi"	Sewage discharge and transportation/sewage discharge and transportation	No
Erie Canal	US	"Northeast US & Southeast Canada Atlantic" + "Laurentian Great Lakes"	Transportation/recreation and transportation	No
Pontcysyllte Aqueduct	UK	"Central & Western Europe" + "Northern British Isles"	Transportation/recreation	Yes
Ghent-Terneuzen Canal	Belgium and Netherlands	"Central & Western Europe"	Transportation/transportation	No
Canal du Midi	France	"Cantabric Coast - Languedoc"	Transportation/recreation and irrigation	Yes
Ludwig-Danube-Main-Canal	Germany	"Upper Danube" + "Central & Western Europe"	Transportation/recreation	No
Grand Canal	China	"Lower Huang He" + "Lower Yangtze"	Transportation/transportation	Yes
Buckingham Canal	India	"Southern Deccan Plateau" + "Southeastern Ghats"	Transportation/drainage and transportation	No
Alexandra Canal	Australia	"Eastern Coastal Australia"	Transportation/recreation	No
Angkor canals	Cambodia	"Mekong Delta"	Drainage, irrigation, and transportation/recreation	No
Lake Biwa Canal	Japan	"Biwa Ko" + "Honshu - Shikoku - Kyushu"	Irrigation, hydropower, and transportation/water supply and recreation	No

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